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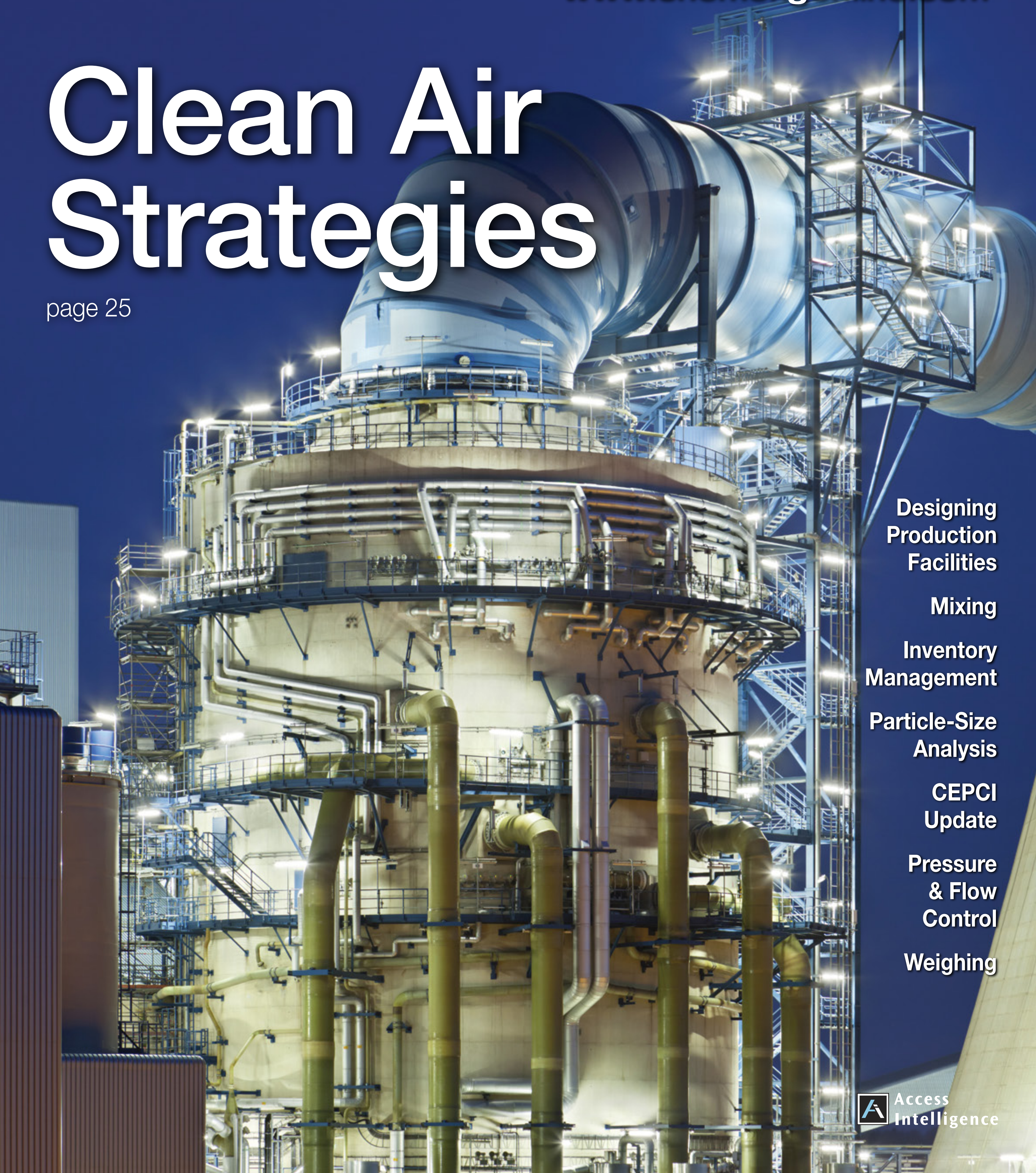

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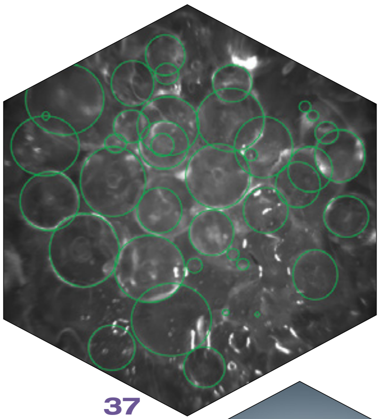

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Editor's Page

Protecting the air we breathe

It has long been known, from advanced monitoring and modeling, that pollutants can linger in the air and travel long distances from their sources. Local air quality can therefore be affected by disturbances that happen in far-away parts of the globe. The atmosphere connects us, worldwide, making air quality a global concern.

Recently, the ability for polluted air to travel far with dramatic consequences was witnessed by many in North America. Wildfires covering an area reported to be over 10 million acres in Canada produced a heavily air-pollutant-laden plume that covered many areas of the United States with a dark, orange, eerie haze that was deemed unhealthy and even toxic by some reports. Areas stretching from Minnesota and Wisconsin to Maryland and New England had all been issued poor air quality alerts at some point during the plume's movement.

Measuring the air quality

Many people, who were perhaps not yet familiar with it, learned about the Air Quality Index (AQI) — the U.S. Environmental Protection Agency's (EPA) measure of air quality. The EPA establishes an AQI for five major pollutants — ozone, particulate matter, carbon monoxide, sulfur dioxide and nitrogen dioxide. The one of major concern from the wildfires was particulate matter less than 2.5 microns in size ($PM_{2.5}$). These fine particles are able to travel deep into the respiratory tract and are associated with numerous adverse health effects. The AQI runs from 0 to 500, with higher values indicating a higher level of pollution and greater concern for potential health issues. An AQI up to 50 is regarded as healthy, over 100 is unhealthy, over 200 is very unhealthy and over 300 is considered hazardous.

At one point last month, the AQI in New York City was reported to be over 400. Residents were advised to stay indoors and wear masks if going outside was essential. At the time of this writing, the wildfires are still raging and many are keeping track of their local AQIs as wind patterns shift.

These recent events and many others, whether from wildfires or other sources of air-pollution plumes, are a stark reminder of how important our air quality is.

The CPI is doing its part

With goals related to sustainability and combating climate change [*1*], the chemical process industries (CPI) are working toward reducing industrial air-pollution emissions. The American Chemistry Council (ACC; www.americanchemistry.com) reports that its member companies are investing in and deploying technologies to lower emissions. According to the ACC, its member Responsible Care facilities have reduced hazardous air pollutant emissions by approximately 24% from 2010 to 2020.

Our two cover stories this month focus on reducing air pollution from industrial sources. The first article (pp. 25–27) offers considerations in choosing between combustion and non-combustion air-pollution-abatement technologies. And the second article (pp. 28–30) discusses a proactive approach to reducing emissions. ■

Dorothy Lozowski, Editorial Director

1. According to the U.S. Geological Survey (USGS; www.usgs.gov),there is no direct relationship between climate change and wildfires, but they say there is a general consensus that fire instances will increase with climate change.

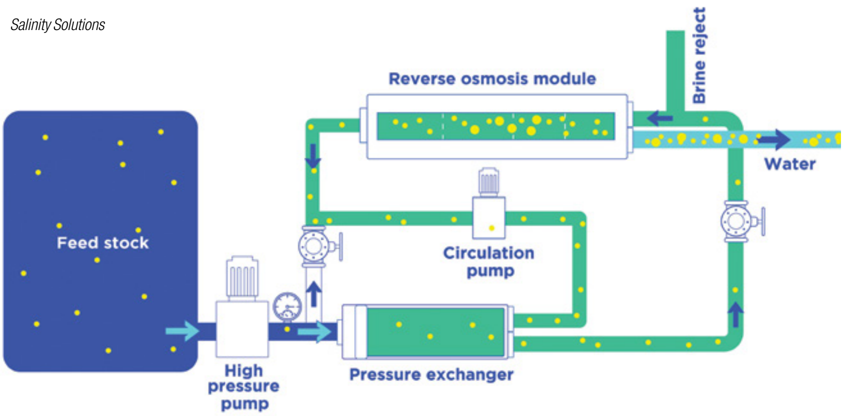
Commercial debut for a batch reverse-osmosis system

Earlier this year, Salinity Solutions Ltd. (Coventry, U.K.; www.salinitysolutions.co.uk) signed an agreement with Te-Tech Process Solutions (Totton, Southampton, U.K.; www.te-tech.co.uk) to manufacture commercial water-purification systems based on batch reverse-osmosis (RO). This technology, originally characterized and developed at the University of Birmingham (U.K.; www.birmingham.ac.uk) and commercialized by spin-off company Salinity Solutions, is said to use 50% less energy and generate 80% less waste than conventional RO, while purifying up to 98% of the water. Co-founder, Liam Burlace says "Batch RO is next-generation technology, allowing for high recovery of freshwater, which considerably reduces energy consumption in comparison to competitive technology."

Salinity Solution's proprietary batch RO process, described in a 2020 issue of *Desalination*, consists of a high-pressure feed pump, a recirculation pump, an RO module and a free-piston pressure exchanger (diagram). In the pressurization phase, the feed pump generates high pressure that is first transferred to the recirculation solution via the pressure exchanger. The pressurized feed then enters the RO module. To complete the batch, the brine exiting the RO module flows back to the pressure exchanger via the recirculation pump. As the concentration inside the recirculation loop increases over time, the feed pump will generate a higher pressure to overcome the increasing osmotic pressure, causing the piston to slide to the right. When the piston reaches the end, the pressurization phase ends, and a purge-and-refill phase occurs.

The first unit — the SAM50 — is said to be the world's first batch RO product manufactured commercially. It uses any standard 8-in. RO membrane and has a typical throughput of 25 m^3/d for a feed with up to 6,000 parts per million (ppm) total dissolved solids (TDS) and a rejection of 95–99.5%. Systems that use six RO elements in two housings have a throughput of 150 m^3/d.

Salinity Solutions



Photochemistry boosts the yield of chiral compounds

Isolation and purification of pure, active enantiomers is important in the development of active pharmaceutical ingredients and drug products. However, recovering the desired optical isomer from a racemic mixture means half of the chemical produced — the undesired isomer — will be wasted, unless it can be recycled in some manner. Now, researchers from the Tokyo University of Science (Japan; www.tus.ac.jp) have developed a system that, at least for one important class of compounds — chiral sulfoxides — is able to produce the desired isomer with high efficiency. This is done by a two-step process, as described in a recent issue of the *Journal of Organic Chemistry*.

In the first step, the desired isomer is separated from the racemic mixture in a high-performance liquid chromatography (HPLC) column containing a chiral stationary phase. The undesired enantiomer then passes through a photoreactor — a glass tube containing an immobilized photocatalyst (2,4,6-triphenylpyrrylium tetrafluoroborate) and transparent glass beads. Irradiation with blue light (402 nm) from a light-emitting diode (LED) causes a rapid photoracemization of the undesired isomer back into a racemic mixture, which can then be recycled back to the HPLC purification column. The cycle can be repeated until the yield of the desired compound is as high as desired.

The researchers demonstrated the technology for synthesizing four enantiometrically pure chiral alkyl aryl sulfoxides, achieving optical purities of 98–99%. High yields (>80%) for the desired compound are achieved after 4 to 6 cycles.

Edited by:
Gerald Ondrey

ORE BENEFICIATION

Last month, Torngat Metals Ltd. (Montréal, Que., Canada: www.torngatmetals.com) and Metso Corp. (Helsinki, Finland; www.mogroup.com) signed a contract for large-volume, pilot-scale processing of ore. The focus of the agreement is to pilot test the beneficiation of ore extracted from Torngat's Strange Lake Rare Earth project in Québec. This project is a critical driver for the electrification value chain, specifically the manufacturing of permanent magnets for electric motors, wind turbines and other low-carbon technologies.

The process incorporates advanced technologies, including X-ray sensor-based ore sorting, magnetic separation and flotation, based on Metso's proprietary technology. This work is being executed in close collaboration with GTK Mintec, the Geological Survey of Finland.

The first phase of work will be completed by the end of 2023, resulting in the production of a rare-earth concentrate. The next phase of work will use the rare-earth concentrate to scale-up and optimize the subsequent process steps to produce a mixed-rare-earth solution, based on Metso's expertise in acid- and heat-based minerals processing and purification. Metso will also provide production-scale engineering and offer technology and equipment solutions for future commercial operations with Torngat.

NEW POLYMER

Thermal and infrared (IR) imaging are used in many industries, but the materials used for this technology (germanium

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or chalcogenide lenses) are expensive and becoming more difficult to find. Now, researchers from Flinders University (Adelaide, Australia; www.flinders.edu.au) have discovered a new, low-cost alternative for IR lenses — a co-polymer of sulfur and cyclopentadiene. Both monomers are inexpensive and plentiful.

The black, high-performance polymers are said to have the unique ability to transmit IR light; it has the highest long-wave infrared light transparency ever reported for a plastic. The material can be rapidly molded into various shapes, such as lenses, instead of the slow milling needed for current lens production.

As described in a recent issue of *Advanced Optical Materials*, the polymer can be synthesized by a copolymerization of molten sulfur and cyclopentadiene, or by a gas-phase process, for which a special reactor was designed. The use of gaseous monomers was previously thought not to be possible by other researchers in the area.

CONCRETE

Last month, Master Builders Solutions (Mannheim, Germany; www.masterbuilders.com) introduced Master-CO_2re, a new superplasticizer technology that can reduce CO_2 emissions in the construction industry. The new product features an intelligent cluster system (ICS) that provides good workability, advanced rheology and "excellent" strength properties for the ready-mix and precast concrete industry.

Although clinker only accounts for 10 vol.% of cement, it is responsible for 90% of the CO_2 emissions from cement production. MasterCO2re ICS technology addresses the problem associated with low-clinker cements products.

POWER FROM SPACE

A space solar-power prototype that was launched

(Continues on p. 8)

CO_2-conversion catalyst for making 'e-fuels'

Infinium (Sacramento, Calif.; www.infiniumco.com) recently announced that it has manufactured ton-level quantities of a proprietary catalyst that is integral in the company's process for making liquid fuels from waste CO_2 and hydrogen derived from renewable power. Infinium plans to manufacture commercial volumes of CO_2-derived diesel, aviation fuel and naphtha — known as electrofuels (e-fuels) — starting at the end of 2023.

The catalyst is a key technology for the first stage of the synthetic fuels process in which waste CO_2 from an industrial point source, such as an ethanol- or ammonia-production facility, is reduced to CO in a reverse water-gas-shift (RWGS) reaction. The proprietary RWGS catalyst is now being manufactured in Infinium's Sacramento facility.

In the second stage of the liquid-fuels process, the CO from the first step undergoes a synthesis reaction with renewably generated H_2. Infinium also has developed a proprietary conversion catalyst that is an alterative to traditional Fischer-Tropsch catalysts, and is specially engineered to limit the formation of long hydrocarbon chains, keeping molecules in the range that can be used for vehicle fuels. This second catalyst has been operated commercially in gas-to-liquids (GTL) facilities and has been commercially manufactured for several years.

"The process is similar to our gas-to-liquids process, but with different inputs," explains Infinium CEO Robert Schuetzle. "We are able to generate hydrocarbons from CO_2 and hydrogen that are in the range of diesel and aviation fuel, as well as naphtha, without significant heavy hydrocarbon production."

The "e-naphtha" derived from Infinium's CO_2-conversion process can also be cracked in traditional petrochemical processes to make propylene and ethylene for the plastics market. This allows users to make CO_2-derived plastic products, rather than traditional petroleum feedstock, Schuetzle notes.

Infinium plans to deliver e-fuels from its facility in Corpus Christi, Tex. later this year, and has 14 other facilities in various stages of development in North America and Europe. Among its first customers is Amazon, who will use the e-fuels for its "middle-mile" trucking fleet.

While the cost of Infinium e-fuels is currently higher than petroleum-derived fuels, costs are expected to decline as costs for "green" H_2 come down, Schuetzle says.

This photocatalytic reactor system makes chemicals without fossil fuels

Last May, Emerson (St. Louis, Mo.; www.emerson.com) was selected by Syzygy Plasmonics (Houston; www.plasmonics.tech) to automate its all-electric photocatalytic reactor technology. Syzygy has developed, scaled and integrated its core technologies, incubated at, and licensed from, Rice University (Houston; www.rice.edu), into a universal photocatalytic reactor platform, which includes the Rigel photoreactor and the proprietary photocatalyst that enables light-driven chemical reactions at unprecedented efficiency. For the Syzygy modular reactors, Emerson will provide hardware, software and services, including its DeltaV distributed control system; industrial software for process simulation and data analytics; Rosemount instrumentation to measure pressure, temperature, level and flow; and Fisher valves to control pressure and improve safety.

The breakthrough for this technology came when Rice University researchers embedded a nanoparticle of a traditional catalyst material into the surface of a larger, light-harvesting plasmonic nanoparticle. This two-part nanoparticle structure, known an antenna-reactor complex, provides more efficient capture and transfer of light energy to the reactive sites on the catalyst, effectively replacing the need for thermal energy from the combustion of fossil fuels with light. Also, researchers realized they could replace traditional rare, expensive catalytic metals, like ruthenium, with abundant, affordable light-reactive metals like iron.

Rigel photoreactors feature a photocatalyst-filled sleeve surrounded by a light box. Each reactor is fully contained in an outer shell. Banks of these reactors can be stacked to offer flexible installation sizes ranging from 1 to 100 ton/d of product, such as H_2, methanol and fuels.

Syzygy has three field trials planned for 2023, located in North Carolina, California and South Korea. Last August, for example, the company announced a joint development agreement with Lotte Chemical, Lotte Fine Chemical and Sumitomo Corp. of Americas to test a fully electric chemical reactor for clean hydrogen production. The reactor will be installed and brought online in the second half of 2023 at Lotte facilities in Ulsan, South Korea.

into orbit in January is operational and has demonstrated its ability to wirelessly transmit power in space and to beam detectable power to Earth for the first time. This wireless power transfer was demonstrated by MAPLE, one of three key technologies being tested by the Space Solar Power Demonstrator (SSPD-1), the first space-borne prototype from Caltech's (Pasadena, Calif.; www.caltech.edu) Space Solar Power Project (SSPP). SSPP aims to harvest solar power in space and transmit it to the Earth's surface.

MAPLE (Microwave Array for Power-transfer Low-orbit Experiment), one of the three key experiments within SSPD-1, consists of an array of flexible lightweight microwave-power transmitters driven by custom electronic chips that were built using low-cost silicon technologies. It uses the array of transmitters to beam the energy to desired locations. Using constructive and destructive interference between individual transmitters, a bank of power transmitters is able to shift the focus and direction of the energy it beams out — without any moving parts. The transmitter array uses precise timing-control elements to dynamically focus the power selectively on the desired location using the coherent addition of electromagnetic waves. This enables the majority of the energy to be transmitted to the desired location and nowhere else.

CO_2 CAPTURE

A CO_2 capture process, jointly developed by Heidelberg Materials (www.heidelbergmaterials.com), Linde GmbH (Pullach; www.linde-gas.de) and BASF SE (Ludwigshafen, all Germany; www.basf.com), and based on BASF's advanced OASE blue technology, will be used for the first time at a large-scale CO_2-capture facility operated by Capture-to-Use (CAP2U)

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A photocatalytic platform for CO_2 utilization

As more and more CO_2 is finding its way into carbon-capture systems instead of the air, the demand for new technologies that actually utilize CO_2 is also rising. A new photocatalysis platform developed by New Iridium (Boulder, Colo.; www. newiridium.com) can efficiently convert CO_2 into high-value chemicals using ambient temperatures and low-cost hydrocarbon feedstock. "We are using photons to activate chemical reactions, as opposed to high temperatures. Our key expertise is in designing new photocatalysts to absorb photons and channel that energy into breaking and forming chemical bonds," explains Chern-Hooi Lim, founder and CEO of New Iridium. The key feature behind New Iridium's CO_2 utilization technology is the ability to selectively activate the C–H bond in hydrocarbons, enabling the addition of CO_2 to ultimately form carboxylic acids.

Many of today's methods for CO_2 conversion involve electrochemical processes that use water as a co-feedstock and require high energy input. The photocatalysis platform requires fewer overall processing steps and uses far less energy. Another benefit compared to conventional thermal methods, points out co-founder and COO Brent Cutcliffe, is the ability to electrify the process. "Renewable electricity can be supplied to the LED technology that powers our reactors, which enables some degree of process intensification versus capturing sunlight ourselves. LEDs can emit at different wavelengths and we tune the photocatalyst to match specific wavelengths," says Cutcliffe. He also points out that the convergence of lower-cost renewables with advances in LED technologies is crucial to the feasibility of photocatalysis today. "Even ten years ago, regardless of how efficient we could make the process, it would be prohibitive to do these types of processes," he adds.

Braskem S.A. (São Paulo, Brazil; www. braskem.com) has joined New Iridium as a partner to scale up and further develop the technology. "We are currently doing hundreds of reactions each day at the laboratory scale. The next step will likely be a 5-ton/yr demonstration mini-plant," says Lim.

Lithium metal for next-generation batteries produced from Li_2CO_3 in pilot facility

In May, Li-Metal Corp. (Markham, Ont.; www.li-metal.com) announced the production of refined lithium metal from lithium carbonate salt using a new electrolysis process at the company's pilot facility in Ontario, Canada. The lithium metal produced at the pilot plant is primarily intended for use in the anodes of next-generation batteries, which aim for greater energy density (increasing from 250–280 W-h/kg in current batteries to 350–400 W-h/kg and beyond for future batteries).

Battery anodes made from lithium metal have distinct advantages over currently produced graphite-based anodes. "Li-metal anodes can reduce CO_2 emissions for the overall process by 10 times or more," says Maciej Jastrzebski, co-founder and chief technology officer at Li-Metal. "And using lithium anodes to replace graphite can enable weight savings of 100 kg or more for each car, which would increase vehicle range significantly." Also, the boost in energy density from using Li-metal anodes could allow enhanced performance from Fe-based cathode materials, thus avoiding the need for scarce and problematic-to-mine minerals like Co and Ni, which appear in the highest-performing cathodes, Jastrzebski notes.

Conventional Li-metal processes involve molten-salt electrolysis of LiCl, which generates chlorine gas. To avoid that, Li-Metal's process begins with Li_2CO_3, electrolyzing the material in a flow cell that produces the metal. "We use the same electrolyte as the conventional process, but use it as a solvent to dissolve the Li_2CO_3," says Jastrzebski. The pilot plant is now producing Li metal, and has a nameplate capacity of 2.5 ton/yr of Li metal at full-scale. Typical future commercial facilities would be designed for a capacity between 500 and 2,000 ton/yr.

An important technological achievement that allowed the process to be scaled successfully is the development of a specialized membrane that separates the two sides of the electrolytic reaction, thus preventing side reactions that can form lithium oxide and solid carbon, which can foul the process if the separation is not sufficiently robust.

In addition to the process for refined lithium metal, the company is also developing a physical vapor-deposition process that can be used for producing layered anodes for batteries.

A new class of proton-conducting materials operates at lower temperatures

A new material could open the door to more effective protonic ceramic fuel cells (PCFCs). PCFCs are a promising energy source that employ specialized ceramic materials to conduct protons (instead of electrons) at much lower temperatures than typical solid-oxide fuel cells. However, currently, there are few known materials with adequate proton conductance. Discovered by researchers at Tokyo Institute of Technology (Tokyo Tech; www.titech.ac.jp), and reported in *Communications Materials*, Ba_2LuAlO_5 is a "hexagonal perovskite-related oxide" that exhibits notable characteristics for proton conduction at temperatures as low as 232°C, whereas other ceramic fuel cells require operating temperatures higher than 700°C. Significantly, this conductance was possible without any chemical doping, added catalysts or other alterations to the material. The key to this performance is that Ba_2LuAlO_5 can absorb more water than other similar materials due to its high intrinsic oxygen vacancies. Higher water uptake contributes to improved proton conductivity.

The research team believes that their study of the unique mechanism of protons' movement through the layers of Ba_2LuAlO_5 will begin to reveal other clues for good proton-conducting material candidates. They zeroed in on materials with a large fraction of intrinsic oxygen vacancies — a converse strategy to conventional knowledge of proton-conducting materials, which typically focus on doping to form extrinsic oxygen vacancies. However, such doping processes can lead to nonhomogenous material composition and instability, so the avoidance of chemical doping when using Ba_2LuAlO_5 is a significant benefit.

The next steps will be to refine the chemical structure of Ba_2LuAlO_5 to further improve proton conductivity. For example, the team expects that the related oxide Ba_2InAlO_5, which is isostructural with Ba_2LuAlO_5, could also exhibit excellent proton conductivity.

— a new joint venture (JV) established by Heidelberg Materials and Linde. The plant will be the world's first industrial-scale carbon capture and utilization (CCU) facility. Around 70,000 tons per year of CO_2 will be captured, purified and liquefied. Linde will sell the majority of the resulting liquid CO_2 as a feedstock for the chemicals industry and into the food and beverage end-use markets.

The process will also use the patented OASE aerozone design — a technology that reduces dust and aerosol-induced emissions from the gas flow — in one of its first industrial applications.

CALCIUM BATTERY

Researchers from Tohoku University's (Japan; www.imr.tohoku.ac.jp) Institute for Materials Research (IMR) has developed a prototype calcium-metal rechargeable battery capable of 500 cycles of repeated charge-discharge — the benchmark for practical use. The breakthrough was reported in the May 23 issue of *Advanced Science*.

(Continues on p. 10)

In the study, the scientists tested the long-term operation of a Ca-metal battery with a copper sulfide nanoparticle/carbon composite cathode and a hydride-based electrolyte.

CuS has favorable electrochemical properties. Its layered structure enables it to store a variety of cations, includiing Li, Na and Mg. It has a large theoretical capacity of 560 mAh/g — two to three times higher than present cathode materials for Li-ion batteries.

Through nanoparticulation and compositing with carbon materials, the researchers created a cathode capable of storing large amounts of Ca ions. When employed with the hydride-type electrolyte, they produce a battery with a highly stable cycling performance. ❐

Autonomous control of a distillation column

Eneos Materials Corp. (formerly the elastomers business unit of JSR Corp.; www.eneos.co.jp) and Yokogawa Electric Corp. (both Tokyo, Japan; www.yokogawa.com) recently reached an agreement to officially adopt Yokogawa's autonomous-control artificial intelligence (AI) technology for use at an Eneos Materials chemical plant. The agreement follows field trials of Factorial Kernel Dynamic Policy Programming (FKDPP), a reinforcement learning-based AI algorithm jointly developed by Yokogawa and the Nara Institute of Science and Technology, which is said to have demonstrated a high level of performance while controlling a distillation column at the Eneos Materials plant.

Over a 35-day (840-h) consecutive period in early 2022, this field test initially confirmed that the AI solution could control distillation operations that were beyond the capabilities of existing control methods (proportional, integral, derivative (PID) controller and advanced process control (APC)) and had necessitated manual control of valves based on the judgements of experienced plant personnel. Following a scheduled plant shutdown for maintenance and repairs, the field test resumed and has continued to the present date. It has been conclusively shown that this solution is capable of controlling the complex conditions that are needed to maintain product quality and ensure that liquids in the distillation column remain at an appropriate level, while making maximum possible use of waste heat as a heat source. In so doing, it has stabilized quality, achieved high yield and saved energy, Yokogawa says.

In this field test, Yokogawa says FKDPP demonstrated the following four benefits. First, FKDPP maintained stable control of the liquid levels and maximized the use of waste heat, even in winter and summer weather, with external temperatures changes of about 40°C. Second, by eliminating the production of off-specification products, FKDPP reduced fuel, labor and other costs, and made efficient use of raw materials. For example, FKDPP reduced steam consumption and CO_2 emissions by 40% in comparison to conventional manual control. Third, FKDPP eliminated the need for operators to perform manual inputs. Fourth, the same AI control model could remain in use, even after modifications were made at the plant during a routine shutdown for maintenance and repair. ■

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Plant Watch

ALPLA to construct PET recycling plant in South Africa

June 13, 2023 — Alpla Group (Hard, Austria; www.alpla.com) is building a new recycling plant in Ballito, South Africa. The plant, with an output of 35,000 metric tons per year (m.t./yr) of recycled polyethylene terephthalate (PET) material, marks the company's entry into the African recycling market. Construction will start in summer 2023 and completion is planned for autumn 2024. In total, Alpla is investing around €60 million in the project.

Wacker to expand polysilicon production capacity in Burghausen

June 12, 2023 — Wacker Chemie AG (Munich, Germany; www.wacker.com) plans to expand its capacity for cleaning semiconductor-grade polysilicon by setting up a new production line at the company's Burghausen site by early 2025. The new plant will increase existing capacity at the site by well over 50%. Capital expenditures for the project are expected to exceed €300 million.

TotalEnergies to double SAF production and add biomethane unit in Grandpuits

June 8, 2023 — TotalEnergies SE (Paris; www.totalenergies.com) is doubling the production of sustainable aviation fuel (SAF) at its Grandpuits site in France, bringing the site's annual production capacity to 285,000 m.t./yr — almost double the previous capacity announced in 2020. There are also plans to construct a biomethane unit at Grandpuits, which will have an annual capacity of 80 GWh.

Toray announces further capacity expansion for PP films

June 8, 2023 — Toray Industries, Inc. (Tokyo; www.toray.com) is again increasing production capacity for Torayfan-branded biaxially oriented polypropylene film at the Tsuchiura Plant in Ibaraki Prefecture, Japan. When they go online in 2025, the upgraded facilities will lift Torayfan production capacity by 40%.

BASF increases production capacity for alkoxylates in Belgium and Germany

June 7, 2023 — BASF SE (Ludwigshafen, Germany; www.basf.com) is gradually bringing additional alkoxylation production capacity onstream in Antwerp, Belgium and Ludwigshafen, Germany, adding production capacity well in excess of 150,000 m.t./yr. Most of the capacity increase is part of the expansion of ethylene oxide and ethylene-oxide derivatives in Antwerp, which also encompasses investment in a second world-scale ethylene-oxide production line, including purified ethylene-oxide capacity.

Solvay to produce green hydrogen for its peroxides operations in Italy

June 6, 2023 — Solvay S.A. (Brussels, Belgium; www.solvay.com) and Sapio are partnering in the joint development of the Hydrogen Valley Rosignano Project, a large-scale hydrogen production plant with locally-sourced "green" energy in Rosignano, Italy. The plant will be built by mid-2026 within Solvay's Rosignano facility. It will have a capacity of 756 m.t./yr of "green" hydrogen, which will be used for the production of peroxides on site.

BASF to expand production capacity for bio-based alkyl polyglucosides

June 6, 2023 — BASF will increase its global production capacity for alkyl polyglucosides (APG) with two expansions at its sites in Bangpakong, Thailand and Cincinnati, Ohio. The additional capacities are expected to come onstream in 2025.

3M to expand biotech manufacturing capacities in Europe

June 5, 2023 — 3M (St. Paul, Minn.; www.3m.com) announced it will invest $146 million to expand its capabilities to further support biotechnology manufacturing facilities in Europe. The new investment will accelerate 3M's development and delivery of filtration equipment designed for bioprocessing, biological and small-molecule pharmaceutical-ingredient manufacturing applications.

Wacker completes VAE expansion in Nanjing

May 30, 2023 — Wacker completed a capacity expansion for vinyl-acetate-ethylene (VAE) copolymer dispersions and VAE dispersible polymer powders at the company's site in Nanjing, China. With a new reactor for dispersions and a new spray dryer for dispersible polymer powders, the expansion more than doubles Wacker's production capacity in Nanjing. Wacker invested around $100 million in its integrated production site for the expansion project. The two new plants are said to be the largest of their kind in the world.

Mergers & Acquisitions

Saint-Gobain to acquire Building Products of Canada Corp.

June 13, 2023 — Saint-Gobain S.A. (Courbevoie, France; www.saint-gobain.com) entered into a definitive agreement for the acquisition of Building Products of Canada Corp., a privately owned manufacturer of construction materials, for approximately €925 million in cash. With this acquisition, Saint-Gobain takes a logical step to reinforce its leadership in light and sustainable construction in the Canadian market.

Elkem acquires carbon-materials manufacturer VUM
June 12, 2023 — Elkem ASA (Oslo, Norway; www.elkem.com) has acquired VUM, a Slovak producer of carbon materials for industrial smelters, including anode paste, electrode paste and ramming paste, as well as recarburizers. Elkem expects the acquisition to contribute an additional turnover of around NOK 360 million ($34 million) per year. VUM operates a plant located near Žiar nad Hronom, Slovakia. VUM also has a calcining technology with rotary-kiln furnaces, which adds flexibility to handle different raw materials.

Sumitomo acquires sulfuric acid company in the U.S.
June 8, 2023 — Sumitomo Corporation of Americas (SCOA), together with its parent, Sumitomo Corporation Japan (Tokyo, Japan; www.sumitomocorp.com) announced its acquisition of Saconix LLC (Roswell, Ga.), a company engaged in the procurement, sale, storage and distribution of sulfuric acid in the U.S., mainly in the U.S. Gulf Coast and western regions.

Chemours to sell its glycolic acid business
June 2, 2023 — The Chemours Co. (Wilmington, Del.; www.chemours.com) has entered into a definitive agreement to sell its glycolic acid business for $137 million to PureTech Scientific Inc. With this acquisition, PureTech Scientific is positioning itself to become a global leader in organic synthesis of ultra-high-purity alpha hydroxy acids for the life sciences and specialty chemical industries. The transaction is expected to close by the third quarter of 2023, subject to regulatory approvals.

Carbios and Indorama Ventures form biorecycling JV
June 1, 2023 — Carbios (St-Beauzire, France; www.carbios.fr) and Indorama Ventures Ltd. (Bangkok, Thailand; www.indoramaventures.com) plan to form a joint venture (JV) for the construction of the world's first PET biorecycling plant in France. The project is to be located at Indorama Ventures' existing PET plant at Longlaville, with expected start of construction by the end of 2023 and targeted commissioning in 2025.

Air Products to acquire industrial gas complex in Uzbekistan
May 30, 2023 — Air Products (Lehigh Valley, Pa.; www.airproducts.com) signed an investment agreement to acquire, own and operate a natural gas-to-syngas processing facility in Qashqadaryo Province, Uzbekistan for $1 billion. The natural-gas-to-syngas industrial complex is an integral part of state-owned energy company Uzbekneftegaz JSC's multi-billion gas-to-liquid (GTL) facility that produces 1.5 million m.t./yr of synthetic fuels.

Lummus acquires water-treatment assets from Siemens Energy
May 24, 2023 — Lummus Technology LLC (Houston; www.lummustechnology.com) has reached an agreement with Siemens Energy AG (Munich, Germany; www.siemens-energy.com) to acquire assets from its water solutions portfolio. The technologies address water and wastewater needs of the oil-and-gas industry using carbon adsorption, biological treatment, hydrothermal processes and more. ■

Mary Page Bailey

Innovations in Mixing Maximize Efficiency

Developments in mixing technologies permit efficient use of energy and resources and manage challenging applications

Mixing equipment hadn't changed much in the past 50 years until recently when chemical processors began demanding more efficiency from their mixing operations due to current industry challenges, including tighter budgets, aggressive sustainability goals and problematic applications. As a result, providers of mixing equipment are finding innovative ways to maximize efficiency and throughput and are rethinking existing mixing technologies for difficult applications.

"The biggest challenge chemical plant operators face in their mixing operations is the efficient use of energy and resources to achieve a reliable and good quality of mixture," says Raul Gonzalo, director of operations and sales with ProSep, Inc. (Houston; www.prosep.com). "Many times operators are limited to conventional mixing methods that do not provide proper contact between the additives and the main process stream, resulting in poor utilization and requiring overdosage of the chemicals to achieve the desired process results. Many of the conventional static mixers on the market use complex internal arrangements that generate modest mixture quality at the expense of high pressure drop and potential accumulation of solids and blockage of the pipeline, resulting in recurring shutdowns for maintenance."

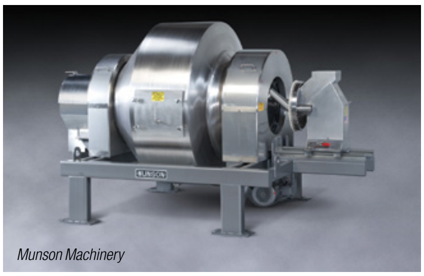


FIGURE 1. Compared to a typical blender, Munson Machinery's rotary batch mixer blends in half the time of a typical ribbon blender, requires half the horsepower and consumes one-quarter to one-third of the energy

Gonzalo continues: "This causes additional issues because efficient use of energy and resources is crucial for the sustainable operation of any process or industry. If not done efficiently, mixing operations can consume a significant amount of energy and resources, leading to increased costs and environmental impact."

Stephen J. Knauth, marketing and technical manager with Munson Machinery Co. (Utica, N.Y.; www.munsonmachinery.com) agrees: "Virtually every processor strives for a mixing process that will achieve total uniformity in the least amount of time with the least degradation, waste, cleaning time, capital cost and operational cost. However, which mixer of the many types available will best achieve those requirements will depend on wide-ranging application requirements, including, but not limited to, material characteristics, capacity, heat generation, degradation, shear, contact with seals or bearings, cycle times, residual material, cleaning time, energy use, footprint, capital cost and operational cost."

Manage specific challenges

Because of the diversity of mixing applications, providers of mixing equipment are trying new approaches to a variety of mixing technologies to help chemical pro-

FIGURE 2. ProSep's high efficiency annular injection mixer is suitable for injecting, dispersing and mixing liquids into multiphase or gaseous streams, and in some cases into liquid streams with low viscosity

cessors manage their specific challenges. For example, in situations where energy usage is of increasing importance relative to processing costs and environmental sustainability, Munson Machinery's rotary batch mixer (Figure 1) blends in half the time of a typical ribbon blender, requires half the horsepower and consumes one-quarter to one-third of the energy, the company says. But in instances where the energy and shear imparted by a ribbon blender may be necessary to break down agglomerates and combine solids with high volumes of liquids, higher energy use may be unavoidable, so the company's variable intensity mixer or its cylindrical plow blender, both of which impart energy and shear, may be a suitable choice relative to power consumption and other processing variables.

ProSep's Gonzalo acknowledges that for many processors, there is an important distinction between mixing and mixing efficiently. "Mixing efficiently refers to the ability to achieve a good quality mixture with an optimum use of energy and our high-efficiency

mixers were carefully developed to achieve this."

ProSep's high-efficiency mixers (Figure 2) come in a variety of designs for different applications and feature an internal arrangement that uses the momentum of the main process stream to shear the injected phase into evenly dispersed droplets, maximizing the area of contact between the injected fluid and the process stream. This method reduces energy consumption and allows optimum use of resources, lowering operational expenses and reducing the carbon footprint. "They provide a reliable mixing solution for chemical-plant process optimization and sustainable operations, so many processors are adopting this technology as their new standard," says Gonzalo.

Along with more efficient mixing operations, chemical processors are also demanding repeatability, according to Shawn McManus, eastern regional chemical market manager with Admix, Inc. (Londonderry, N.H.; www.admix.com). "The name of the game at the end of the day is to reduce processing time, to fully utilize the raw materials and to minimize error, because waste is a big — and costly — problem for chemical processors," notes McManus. "This means repeatability is key. When you make a product, you need it the same every time, and to do that, the machine you are using must perform in the same manner every time and it has to do so with as much efficiency as is possible."


Admix

FIGURE 3. Admix's Rotosolver features a cylindrical design, which provides more surface area, allowing more potential for impact and offers dual-action pumping to provide three times as much pumping capacity, maximizing efficiency

He says Admix's Rotosolver (Figure 3) provides a unique, modern solution that addresses both efficiency and repeatability. Traditional high-shear technologies are very low pumping and require a tight tolerance between the rotor and stator to achieve shear. In traditional high-shear mixers, the particles must impact the surface area of the blade and then accelerate into other particles to properly break apart and break down, which is inefficient and can introduce variability into the process. "While traditional technologies have a flat design, the Rotosolver features a cylindrical design, which provides more surface area, allowing more potential for impact. It also offers dual-action pumping to provide three times as much pumping capacity, which maximizes efficiency as it results in an equivalent amount of shear with 25% less energy consumption [when compared to older technologies]," says McManus. "Long-term repeatability is achieved because there is no stator, this means the Rotosolver doesn't depend on mechanical shear, but instead generates hydraulic shear, which allows the machine to operate in the same manner over time because there is no wear and tear on the stator. Traditional rotor/stator designs that rely on mechanical shear can wear over time, creating variable results."

Meanwhile, small batch processors face their own sets of challenges, with efficient mixing and flexibility as top priorities, says Mark Hennis, president of INDCO, Inc. (New Albany, Ind.; www.indco.com). "In traditional small batch mixers, high speed and high torque don't co-exist in the same mixer," he says. "For lower viscosities, a high-speed motor is usually used with a small impeller to move the liquids quickly and efficiently, but a lot of small batch mixing requires the flexibility to also support a higher-viscosity, higher-torque situation. In the past, this required a second mixer that featured a larger impeller to provide more contact and a gear drive to increase the torque to achieve the proper mix."

However, INDCO introduced its HSM-03V mixer (Figure 4), an "all-in-one" mixer that works for applications ranging from dispersion, high-speed and high-shear mixing all the way to high-torque and high-viscosity mixing, says Hennis. "We get many processors who want to retrofit equipment for new applications, but the existing mixer doesn't always have the capability because it lacks either the torque or the speed required to switch from one to the other. Our flexible, versatile mixer features a d.c. motor with a torque- or speed-priority control mechanism and is capable of mixing or moving very high-viscosity materials or going extremely fast with high shear to mix things like emulsions, such as when imparting pigments into paints. It can handle both ends of the spectrum and provides a wide range of process flexibility in one machine."

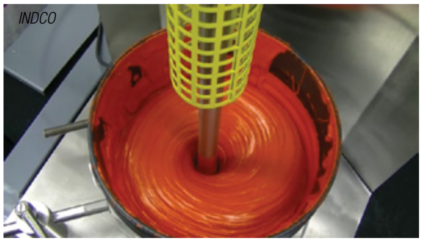

INDCO

FIGURE 4. INDCO's HSM-03V mixer works for applications ranging from dispersion, high-speed and high-shear mixing all the way to high-torque and high-viscosity mixing

Continuous mixing

"In applications where the components can be continuously measured, metered and combined, an inline process would be more efficient than a batch process," says Erin Dillon, media and marketing coordinator with Charles Ross & Son Company (ROSS; Hauppauge, N.Y.; www.mixers.com). "However, many processes do not fit into that category and a batching step of


Charles Ross & Son Company

FIGURE 5. The ROSS inline ultra-high shear sanitary mixer, Model HSM-715XSUHD-250, is designed to deliver dispersion, emulsification and homogenization at high throughput

Entex

FIGURE 6. Entex's planetary roller extruder successfully performs in continuous chemical extrusion processes as it offers rapid mixing of reactants, targeted and precise temperature control and high-performance devolatilization/degassing. Shown here is the laboratory-scale model

some scale is still required. However, a ROSS inline high-shear mixer or ultra-high shear mixer can optimize the process, reducing the volume of the batching tank and increasing efficiency and quality of the dispersion."

Designed for continuous operation, the ROSS inline ultra-high shear sanitary mixer, Model HSM-715XSUHD-250 (Figure 5), is designed to deliver dispersion, emulsification and homogenization at high throughput. Featuring the X-Series rotor/stator in stainless steel, it takes product through the center of the stator and moves it outward through radial channels in the rows of concentric rotor/stator teeth. The combination of high tip speed and extremely close tolerances between the interlocking channels subjects the product to intense shear in every pass.

Frank Fuchs, head of sales and marketing with Entex Rust & Mitsche GmbH (Entex; Bochum, Germany; www.entex.de) agrees that some processors will gain efficiency by moving towards a continuous process. "In general, discontinuous treatment processes are still the standard in the chemical industry, but there is a trend towards continuous processes as a result of various process technology developments and economic advantages," he says. "Also, demanding compounding, reaction and degassing processes, which are not possible with discontinuous processes, can be realized with the right equipment in only one process step."

Entex developed its planetary roller extruder (Figure 6) for this purpose and it is finding success when performing chemical extrusion processes, as it offers rapid mixing of reactants, targeted and precise temperature control and high-performance devolatilization/degassing. The multi-modular structure and process zones can be regulated both thermally and mechanically so each process section can be individually configured for the reaction sequences in chemical processes. "Be it mixing processes with endothermic and exothermic reactions or chemically induced foaming processes, the degassing of chemical reactions or chemical recycling processes, the planetary roller extruder's unique properties allow a range of technical process options for implementing chemical reactions in continuous extrusion processes," says Fuchs.

Martin Doll, business segment manager, chemical applications, with Coperion GmbH (Stuttgart, Germany; www.coperion.com), agrees that while there are advantages to continuous mixing processes, there is resistance to making the switch from batch to continuous, but for those who see an increase in demand, it is a worthwhile investment — if it's done properly.

"We are learning from experience that almost anything can be done continuously, but that hinges on the readiness of companies to try to get things done differently and it also requires an initial investment that pays off when continuous demand is needed," says Doll. "As soon as demand starts to increase, we are approached by very traditional companies who ask for an alternative production method and that is often a continuous process. In applications with a continuous demand, there are a lot of advantages to moving away from batch. For example, continuous production saves a lot of time on cleaning between batches and continuous systems can be fully automated. In addition, it is possible to perform operations that are not easy or possible to do in batch processes, such as chemical reactions or processes that require very low temperatures.

Coperion

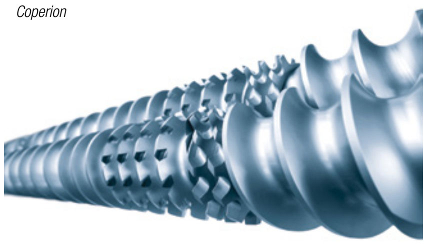


FIGURE 7. Coperion offers a twin-screw extruder for continuous processes that features a design that allows more material to be processed with much shorter throughput times

To further boost the efficiency of continuous operations, Coperion offers a twin-screw extruder (Figure 7), which features a design that allows more material to be processed with much shorter throughput times. "There are very small gaps between the elements so a lot of shear can be applied to the material, which allows even distribution in a shorter amount of time," says Doll. "Performing the same operation in a batch process might require 30 minutes to several hours, but with the twin-screw extruder, materials can be properly mixed in just minutes."

While the extruder is the heart of a continuous mixing process, it does require an adequate feeding system. "In continuous processes, it is necessary to make sure the right amount of ingredient is being brought into the process at all times, and that requires very accurate feeding because if one feeder is not adding the right amount of material at the right time, it changes the composition of the final product," says Doll.

To combat this issue, Coperion offers feeders with special controls and gravimetric feeders that measure the weight of the ingredients in a reliable, accurate and robust way. Together, the twin-screw extruder and feeder offer a turnkey system for efficient and reliable continuous mixing.

Challenging applications

Another difficulty faced by some chemical processors is the introduction of challenging mixing applications. "Two big issues right now have processors rethinking their mixing operations — nanotechnologies and natural ingredients," says John Paul, CEO and managing director of PerMix (Chicago, Ill.; www.permixmixers.com). "These two applications are perplexing a lot of chemical manufacturers and pushing existing mixing technologies to

PerMix

FIGURE 8. PAM Series vertical paddle mixers from PerMix are efficient and versatile blending machines for batch mixing of free-flowing powders, granules and pellets and allow the material particles and ingredients to be mixed with minimal mechanical and thermal stress

their limits."

He continues: "On the nano side, we have to push for higher vacuum and higher temperatures, as many of the nano-based products require mixing technologies that can handle temperatures of 350°C under full vacuum for anywhere between 16 to 24 hours of time in order for the molecules to properly bond. On the natural side, we are taking ingredients with various densities and characteristics and, without adding binders or artificial ingredients, we have to find a way to mix them quickly and efficiently.

"Not only do we need to accommodate these different, but current and relevant needs, but we must keep in mind that when we go into a facility, the processors usually have an established footprint and process in place, so tearing apart the existing line to trade in a new mixer is not an option. And, on top of that, we have to keep efficiency and sustainability top of mind."

To meet these challenges, PerMix developed a vertical paddle mixer that operates as both a vacuum mixer and a dryer. PAM Series vertical paddle mixers (Figure 8) are efficient and versatile blending machines for batch mixing of free-flowing powders, granules and pellets. They allow the material particles and ingredients to be mixed with minimal mechanical and thermal stress, which makes this type of mixer a viable solution for fragile and heat-sensitive products.

Designed with a single shaft with only one ribbon, the mixer can provide multi-dimensional movement of the materials. The ribbon inside the mixing vessel moves the materials upward from the bottom to the top. The materials then drop by gravity into the center, generating a counter flow of the product particles. The ribbon design ensures that the linear speed of the particles are different from one point to another, which results in a turbulence flow field. During operation, material particles and heat are exchanged quickly, creating a homogeneous product. In addition, a high-speed chopper can be added to provide intensive mixing and/or lump breaking in applications that require a liquid to be added to powdery materials.

Thanks to recent innovations, chemical processors are finding ways to maximize the efficiency of their mixing operations to help reduce costs and increase sustainability while providing new and better chemical products. ■

Joy LePree

Pressure & Flow Measurement

Ashcroft

Bronkhorst High-Tech

Chell Instruments

WIKA Alexander Wiegand

A new fluoropolymer pressure transducer with display

The ZL95 fluoropolymer pressure transducer (photo) provides reliable and repeatable pressure measurements in corrosive environments. This transducer features a four-digit LED display with NPN switch outputs, capacitance sensor for excellent thermal stability and PTFE/PFA (polytetrafluoroethylene/perfluoroalkoxy alkanes) wetted parts that combine with the company's patented vent design to provide extended cycle life and corrosion resistance to chemicals, such as hydrofluoric acid. The transducer is compatible with pipe diameters from 0.25 to 0.5 in. O.D. and has multiple mounting options, including tube connections, press fit nuts, flared nuts and threaded nuts. The ZL95 is suitable for cleaning equipment for semiconductors, cleaning equipment for flat-panel displays, wet stations and chemical supply systems. — *Ashcroft Inc, Stratford, Conn.*
www.ashcroft.com

Flowmeters with media-isolated pressure sensors

The IQ+FLOW series of miniature mass flow and pressure meters and controllers is used by equipment manufacturers in the analytical, biotechnology and life science market. The footprint of single channel instruments is only 20 mm by 40 mm, which is advantageous for manufacturers of desktop equipment. The IQ+FLOW product line has now been extended to pressure instruments with media-isolated pressure sensors. The sensor chip is protected by a stainless-steel diaphragm and oil-filled compartment. With this new option, the instruments can handle a much wider variety of media than before, including light gases, such as hydrogen and helium. IQ+FLOW series is available in three configurations: single-channel versions (photo, left) for either inline or top-mount integration and multi-channel versions. Compact two- or three-channel instruments (photo, right) can be configured on user specification to measure or control the mass flow or the upstream or downstream pressure in a system. — *Bronkhorst High-Tech B.V., Ruurlo, the Netherlands*
www.bronkhorst.com

This pressure scanner is in a smaller package

The microDAQ3-16 (photo) combines high-accuracy digital sensors and an advanced-processor design to give the most accurate results possible. The microDAQ3-16 delivers the same performance as the 64-channel version. However, this latest edition is a more compact package, improving its versatility and suitability for increasingly demanding applications. The microDAQ utilizes technology developed in house, within the company's microDAQ and nanoDAQ ranges, such as an embedded web server, IEEE 1588 PTP time stamping, power-over-ethernet, CAN, hardware trigger and EtherCAT. The device makes use of highly accurate transducers, which are combined with both a pressure and temperature 24-bit analog to digital converter (ADC), to give a precise temperature measurement and almost entirely compensate for thermal effects. Additionally, the microDAQ3-16 is capable of outputting differential or absolute compensated engineering unit pressure data at speeds of up to 400 Hz per channel. — *Chell Instruments, Ltd., North Walsham, U.K.*
www.chell.co.uk

A pressure transducer for high-purity applications

The WUD-2x-E (photo) is a compact, ultrahigh-purity transducer for high-accuracy pressure measurement of ultrapure gases in the semiconductor industry. Due to minimal signal noise, the sensor provides precise measured values in the long term. Thanks to active temperature compensation, this can be done even with high temperature fluctuations. The measured values can be viewed on the display. By using EtherCAT, the model WUD-2x-E does not have to be disconnected from the network for firmware updates or troubleshooting. This avoids production downtime due to incorrect installation or removal,

maximizes process safety and allows updating of the instruments. In addition to pressure values, temperature data or error status can also be transmitted. — *WIKA Alexander Wiegand SE & Co. KG, Klingenberg, Germany*
www.wika.de

Four-tube technology for measurement of high flows

Promass Q (photo) is a Coriolis flowmeter line that alleviates concerns of inaccuracies with its four-tube technology. It is available for larger pipes than ever before — up to 10 in. (DN 250) — for measuring flowrates up to 18,900 barrels per hour (2,400 ton/h). And the new four-tube technology opens the door to additional applications in the oil-and-gas industry. These include high-precision metering for custody transfer, fiscal metering, master metering as a reference device for on-site verification, and more. In addition to mass and volumetric flow, Promass Q also records process density and temperature. This enables the incorporation of fluctuating process and ambient conditions into flow measurement, with appropriate compensation, helping to achieve tight error bands of ±0.05% for mass flow and ±0.2 kg/m^3 for density. — *Endress+Hauser, Greenwood, Ind.*
www.us.endress.com

A flow sensor with plain text display

The FS101 flow sensor (photo) is the latest member of this company's FS+ fluid sensor family. The new FS+ devices have the same look and feel and are therefore just as easy to run and commission as all other sensors in the family. The four-digit, 12-segment display on the devices shows the current flow value clearly as a percentage of the setpoint. The implemented IO-Link smart sensor profile simplifies the conversion of the IO-Link flow sensors of other manufacturers to FS+ devices, since process data, parameters and functions are standardized. The sensors can be used, for example, to monitor flows in coolant circuits or for dry-run protection in pumps. The FS101 retains the two unique Quick Teach and Delta Flow functions that already simplified commissioning in the FS100 with a bar-graph display. — *Hans Turck GmbH & Co. KG, Mülheim an der Ruhr, Germany*
www.turck.com

Intelligent flow converter for safety applications

The new IFC 400 electromagnetic flow converter (photo) combines with this company's Optiflux 4000 to create the Optiflux 4400 electromagnetic flowmeter. The IFC 400 helps detect external influences, such as excessive vibration, temperature extremes and magnetic field effects, and also detects process influences like chemicals and excessive sedimentation in the liquid. To detect these influences, the IFC 400 has a self-diagnostic function covering three aspects: process conditions, device functioning and out-of-specification testing. The process measurement check detects leakages, contamination, liner deformation and air entrainment in the process liquid. The device function self-check continuously monitors electronics and sensor hardware. Out-of-specification testing detects any sudden unexplained flow changes, linearity issues and uncertain measurements. — *Krohne Inc., Beverly, Mass.*
www.us.krohne.com

High-pressure gas flowmeter for natural gas distribution

The Flowsic550 ultrasonic gas flowmeter (photo) expands this company's portfolio, offering a suitable solution for small nominal diameters and compact installations in the high-pressure range. This is especially helpful at natural-gas-distribution sites and transmission systems. With the use of ultrasound technology and the absence of mechanical components, the Flowsic550 is said to offer clear cost advantages over conventional turbine and rotary-displacement meters. When utilized in transfer and measuring stations, Flowsic550 ensures a continuous and blockage-free gas supply. The device handles an operating pressure up to 1,480 psi. It is a multi-path meter with integrated flow conditioning, suitable for compact meter stations. It is not only easy to install, but is also compatible with turbine gas meters. Therefore, it can easily be integrated into most existing compact measuring installations. — *SICK, Inc., Houston*
www.sick.com

Endress+Hauser

Hans Turck

Krohne

SICK

Sensirion

Fluid Components International (FCI)

Emerson

Flexim

A small flow sensor for flowrates up to 1 L/min

The SLF3S-4000B liquid flow sensor (photo) accurately measures flowrates up to 1 L/min with the usual quality, while measuring just 5 cm in length and weighing 7 g. Normally, either higher flow velocities or larger channel cross-sections are required to accurately measure high flowrates; both factors, however, increase the likelihood of turbulence. To overcome this hydrodynamic limitation, this company employs a design trick — the new channel profile has a W shape. This allows the micro-electromechanical system (MEMS) chip to be positioned along the narrower side stream (with laminar flow), where it can really demonstrate its measurement performance. The new sensor covers flowrates from microliters per minute to 1 L/min. Initial field trials are also being planned for a device handling flowrates up to 20 L/min. — *Sensirion AG, Stäfa, Switzerland*
www.sensirion.com

Precise gas line control for ovens and furnaces

The compact ST75 air/gas flowmeter (photo), which measures fuel gas, process gas, inert gas, waste gases and air in small line sizes, is suitable for optimizing natural-gas flow control for industrial ovens, heat chambers and furnaces to reduce process and plant fuel costs. No matter the type of oven, heat chamber or furnace, they all benefit from the precise control of natural gas flow. The ST75 helps process and plant engineers more accurately control their complex heating processes to optimize rise time, which lowers gas consumption and minimizes plant energy costs. In addition, reducing natural gas consumption shrinks a plant's carbon footprint to protect the environment. The ST75 is equally well suited for low- and high-flow operations in industrial ovens and operates over a wide flow range, from 0.01 to 559 std. ft^3/min depending on line size. For variable process conditions, the ST75 is factory preset to a wide turndown range at 10:1 to 100:1. The ST75 flowmeter features accuracy to ±2% of reading with ±0.5% repeatability over varying process temperatures in line sizes from 0.25 to 2 in. — *Fluid Components International (FCI), San Marcos, Calif.*
www.fluidcomponents.com

Reduce maintenance of DP measurements

The Rosemount 319 Flushing Ring with valve-integrated design (photo), ensures accurate differential pressure (DP) measurement and lower maintenance. Available in traditional and compact options, the new 319 Flushing Rings provide a process-to-seal connection and allow for faster diaphragm-seal maintenance without disconnecting them from process flanges. The traditional design utilizes a flow-through cleaning action and can be sized to fit almost any application. Configurations are offered with a choice of ball valves, needle valves or gate valves, and in multiple materials, flange types, sizes and ratings. The compact design removes residual build-up quickly, cleaning five times faster over 30% more surface area and 50% fewer leak points than other flushing rings. — *Emerson, Shakopee, Minn.*
www.emerson.com

Real-time determination of gas-quality parameters

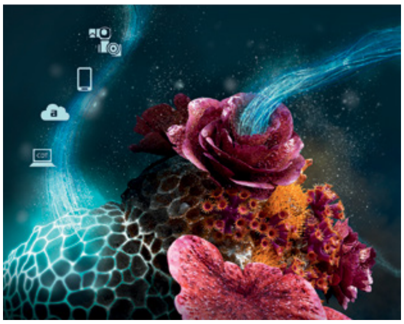
With the Natural Gas Engine (NGE) function of the Fluxus G gas flowmeter series (photo), this company now offers the possibility of determining gas parameters, such as compressibility, molecular weight and density simultaneously with the flow in real time, enabling the meter to output the correct standard volume flow. The analysis function of the NGE is based on the measurement of the speed of sound — the same clamp-on transducers mounted on the outside of the pipe that are used to determine the volume flow by measuring the transit time difference simultaneously record the speed of sound of the medium flowing inside. The company has developed a self-learning algorithm that links the speed of sound with gas quality parameters. A series of tests in independent test laboratories confirmed the performance and accuracy of the NGE, for example, when measuring the flow of natural gas-hydrogen mixtures. — *Flexim GmbH, Berlin, Germany*
www.flexim.com ■

Gerald Ondrey

PPG

Schenck Process

Automation Technology



AUMA Riester

Coatings to protect against vibration, shock and more

This company has significantly expanded the offerings in its Flooring line of concrete coatings (photo). The expanded range comprises integrated systems of primers, bases and topcoats for environments that require electrostatic protection, for equipment mechanical rooms and for applications where a combination of high performance and ultra-fast return to service is essential. Durable and easy to clean, the Flooring systems are also optimized for especially challenging applications. For example, in environments where electrostatic discharge is a hazard, such as electronics manufacturing facilities, a three-coat electrostatic-protection system (comprising an epoxy primer, an electrostatic dissipative grounding plane and a choice of topcoats) provides additional chemical and wear protection. The Flooring product range also includes the Mechanical Equipment Room (MER) system, which comprises an epoxy primer, waterproofing membrane and two-component topcoat to provide the combined resistance to moisture, temperature, chemicals and vibration that these environments require. — *PPG, Pittsburgh, Pa.*
www.ppg.com

Versatile feeder handles a wide range of bulk solids

The MechaTron dry material feeder (photo) has all the unique design features that manufacturers require for their processing applications. Complete disassembly from the non-process side of the feeder eliminates the need to remove upper extension hoppers, bins, bulk bags and intermediate bulk containers (IBCs) to clean or maintain the feeder. Flexible or all stainless-steel hoppers are available to accommodate any unique dry-material feeding application. MechaTron feeders handle a wide range of volumetric or gravimetric feeding applications for bulk solid materials, such as TiO_2, wood flour and carbon black. The MechaTron can achieve feedrates from 0.002 to 1,100 ft^3/h. — *Schenck Process LLC, Whitewater, Wis.*
www.schenckprocess.com

Minimize the carbon footprint of pipeline operations

The Zero Emission Electro-Hydraulic actuator (photo) provides a comprehensive solution to lower emissions without requiring pipeline gas as the actuator's primary power supply. Pipeline actuators have previously relied on using the gas from the pipeline as a power source, which is then emitted into the atmosphere. With the self-contained Zero Emission Electro-Hydraulic solution, the power source is attached to the actuator in a compact platform. Available in spring-return or double-acting configurations, the Zero Emission Electro-Hydraulic package can be mounted directly to the valve via flange or custom connection. The pump, motor, reservoir limit switches, solenoids and positioners are mounted to the actuator. In remote locations where power is not available, solar power systems can be applied to run the systems. A skid-mounted hydraulic-power unit for larger operations is also available, enabling power for multiple actuators simultaneously. — *Automation Technology, Inc. (ATI), Houston*
www.atiactuators.com

A digital ecosystem for enhanced actuator performance

The Coralink digital ecosystem (photo) provides closely networked support for this company's actuators, helping plant operators across all phases of the plant's lifecycle, from commissioning and predictive maintenance to active lifecycle management. At the heart of Coralink is the ability to evaluate the extensive operating data that actuators record automatically in their role as intelligent field devices. The data can easily be read from each actuator, including via a smartphone, and then analyzed. Thanks to its scalability, Coralink saves time and money, even when operators simply use it to check the condition of individual actuators. In advanced applications, Coralink can be used for comprehensive monitoring of all the actuators on a plant, as well as to implement IIoT solutions. — *AUMA Riester GmbH & Co. KG, Ostfildern, Germany*
www.auma.com

Smart inspection system for maintenance in hazardous areas

Together with its strategy partner Senseven, this company has introduced the Valve Sense mobile inspection system (photo). Industrial users can now use the software and AI-based system in conjunction with this company's IS540.1 smartphone to monitor critical valves in international explosive hazardous areas. This solution uses advanced sensor technology based on the proven acoustic emission method, which can be easily applied by maintenance personnel via software guidance — without special training or expert knowledge. Companies can use the mobile inspection set consisting of a smartphone, measuring electronics, waveguide, sensors and a software package to regularly check their plants themselves during ongoing production, thus saving time and money. Intact valves ensure smooth operation, guarantee product quality and also provide safety for employees. Valve Sense helps to detect valve leakage of water, gas, steam or air at an early stage and to react promptly. — *i.safe Mobile GmbH, Lauda-Koenigshofen, Germany*

www.isafe-mobile.com

Robust hearing protection with Bluetooth connectivity

Noise-COM 500 products (photo) are Bluetooth-enabled hearing protectors specifically designed for use in extremely harsh, noisy operations. They are suitable, for example, for use in construction, mining or other heavy industries where using hearing protection is vital, and the ability to communicate with clarity is of equally high importance. These robust and durable hearing protectors combine excellent ambient-sound quality with an outstanding noise-canceling microphone for clear speech. As the Noise-COM 500 can be connected to various Bluetooth two-way radios or mobile phones, users can comfortably listen to audio, as well as make and receive phone calls. Additionally, the ambient sound feature allows users to clearly hear surrounding sounds, such as speech or warning signals while blocking high-level, harmful noises out. There is also an easily accessible rotary button for push-to-talk and ambient-sound volume adjustment. With the Noise-COM 500XP model, there is an option to define ambient-sound audio profiles for different occasions, enabling the best possible audio for most operational situations. — *Savox Communications Inc., Raleigh, N.C.*

www.savox.com

Optical flame detection over longer distances

The Spyglass SG50-F triple infrared (IR) and ultraviolet (UV) open-path flame detectors (photo) offer fast and high-performance optical flame detection over extensive distances, and superior false-alarm immunity when operating in challenging environments. All Spyglass flame detectors are available with optional built-in color or near-IR video, which allows users to see fires remotely and make critical safety decisions from a distance. Color video is proficient at seeing gasoline and jet fuel fires, while the near-IR video option identifies fires caused by hydrogen and methanol, which may not be visible to the naked eye. — *Teledyne Gas and Flame Detection, Cypress, Tex.*

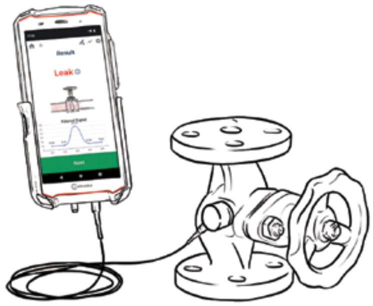
www.teledynegfd.com

Protect tanks against overpressure or excess vacuum

12F-TWW-0 pressure/vacuum relief valves (PVRV; photo) are designed to increase protection against damage to tank equipment caused by overpressure or excessive vacuum. These new devices are said to achieve superior sealing performance and industry-leading flowrates within a smaller valve footprint utilizing 10% overpressure technology. With this device, costly product evaporative losses due to normal tank "breathing" are greatly reduced and fugitive emissions are minimized, the company says. Made from aluminum, carbon steel and stainless steel, the Model 12F-TWW-0 PVRV is available in sizes from 2–12 in., in pressure settings from 0.5 to 24 oz/in^2 and vacuum settings of 0.464 to 24 oz/in^2. It also offers superior tightness, exceeding API-2000 leak requirements, and is PED and ATEX certified. — *Groth Corp., Stafford, Tex.*

www.grothcorp.com ■

Mary Page Bailey and Gerald Ondrey



i.safe Mobile

Savox Communications

Teledyne Gas and Flame Detetion

Groth

Standard Masses for Calibration of Weighing Instruments

Department Editor: Scott Jenkins

Accurately and efficiently weighing raw materials and reagents is a key part of many chemical processes, research projects and laboratory analysis. Poor weighing accuracy can contribute to lost revenue, increased labor costs and lower product quality. Calibration of weighing instruments with standardized weights can establish a relationship between a known value (standard) and a measured value. This one-page reference provides information on the weights that are used to calibrate weighing instruments.

Metrological traceability

Metrological traceability refers to a property of a measurement whereby the result can be related to a reference through a documented unbroken chain of calibrations. A metrologically traceable calibration allows users to know how accurately a weighing instrument is measuring. Each country has a designated National Metrology Institute (NMI), which develops and maintains national standards of measurement. In the U.S., the NMI is the National Institute of Standards and Technology (NIST; Gaithersburg, Md.; www.nist.gov).

According to NIST, its job in this area is twofold: "to ensure U.S. national standards are accurate realizations of the units of the international system (SI) of units, and to transfer the values of those standards to the U.S. measurement system through calibrations, reference materials and other measurement services."

Direct users of NIST's measurement services tie their internal measurement standards to NIST standards and hence, to the SI units. These users, in turn, implement their standards to provide measurement services to their customers, to meet regulatory requirements, and to provide quality assurance in their manufacturing processes, NIST says.

Test weights

Calibration weights are standardized masses used to check the accuracy of a weighing instrument. Reference weights are ultimately traceable to the consensus value of the kilogram (CV). In the past, the kilogram has been defined by the International Prototype Kilogram (IPK), but in 2019 the kilogram was redefined based on the fixed numerical value of the Planck constant [*1*]. Doing so gives (in principle) any NMI the potential to realize the kilogram. The NIST Mass and Force Group disseminates the kilogram to the U.S. measurement system through calibrations of customer weights and weight sets. According to NIST, the organization maintains traceability to the CV using its NIST-4 Kibble Balance, which is used to transfer the CV to the NIST Pool of Mass Standards. The pool consists of platinum, iridium and stainless-steel artifacts that are used to create working standards [*2*].

TABLE 1. DIFFERING TOLERANCES FOR ASTM CLASS 1 REFERENCE WEIGHT VERSUS CLASS 6 WEIGHT.

Class	Weight Tolerance	"In-Tolerance" Range
ASTM Class 1 (1 g weight)	0.034 mg	0.999966 g – 1.000034 g
ASTM Class 6 (1 g weight)	2.0 mg	0.998 g – 1.002 g

Tolerances

Test weights are classified based on tolerances. Weight tolerances can be thought of as the maximum permissible error for a measurement (Table 1). Weight tolerance indicates how much deviation is allowed in the mass of the weight, while still being considered an accurate representation of that mass [*3*].

Two common classification systems for reference calibration weights are maintained by ASTM International (West Conshohocken, Pa., www.astm.org) and the International Organization for Legal Metrology (OIML; Paris, France; www.oiml.org).

The OIML classes are designated as E1, E2, F1, F2, M1, M2 and M3. E1 has the tightest tolerance, while M3 has the widest. Most laboratory applications require OIML weights of Class F2 or below. OIML class weights are more commonly used in Europe and Latin America.

ASTM International has developed 10 calibration weight classes, as guided by document ASTM E 617 [*4*]: ASTM Class 000 thru ASTM Class 7. Class 000 has the tightest tolerance and Class 7 the widest. Most laboratory applications require ASTM weights of Class 4 or below. ASTM class weights are the most common type of calibration weights used in U.S. laboratories.

NIST field standard weights are used primarily to test commercial weighing devices for compliance with commercial requirements. These tests for calibration purposes can be performed by in-house technicians, maintenance workers, local weights and measures officials, device installers and service technicians [*5*].

Handling reference weights

Weights should be handled in ways that avoid changing their metrological characteristics. The weights should not be placed on surfaces that will cause scratches or on dirty surfaces. When cleaning weights, special attention should be paid to proper cleaning. Smaller weights should be handled with gloves (not bare hands) to avoid any finger grease from getting onto the weights and to avoid warming the weights to a higher temperature than the environment. When not used, the weights should be stored in their original storage boxes and only authorized personnel should have access to them. The temperature of the weights should be stabilized to the same temperature at which the calibration is to be done [*6*]. ■

References

1. Jenkins, S., Facts at your Fingertips: Redefining the Kilogram Standard, *Chem. Eng.*, September 2018, p. 30.
2. Abbott, P., Calibration of Mass Standards, National Institute of Standards and Technology, www.nist.gov, accessed May 2023.
3. Troemner, Weights Reference Center, www.troemner.com, accessed May 2023.
4. ASTM International, ASTM E617-18 Standard Specification for Laboratory Weights and Precision Mass Standards,
5. Barton, J.W. and othersl., Specifications, Tolerances and other Technical Requirements for Weighing and Measuring Instruments, NIST Handbook 44, section 2, NIST, 2021.
6. Beamex Inc., Weighing Scale Calibration, white paper, Beamex, www.beamex.com, accessed May 2023.

Technologies for Air-Pollution Control

Effective control technologies are crucial for mitigating the adverse effects of air pollution. The selection of combustion-based or non-combustion-based technologies requires careful consideration of numerous factors

Anoosheh Oskouian and Anu D. Vij
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Air-pollution control technologies are critical for reducing the negative impacts of industrial operations on human health and the environment. However, choosing between combustion-based and non-combustion-based technologies can be a challenging decision, because both approaches have their advantages and disadvantages.

The detrimental effects of air pollution, caused by various sources, such as industrial emissions, vehicle exhaust and biomass burning, have spurred the development of innovative control technologies. These technologies aim to minimize the release of harmful pollutants into the atmosphere and improve air quality.

This article explores some of the different combustion- and non-combustion-based air-pollution control technologies. Depending on the waste-gas pollutants being controlled, the most suitable air-pollution control system will require special design, engineering, installation and startup considerations.

The choice between combustion-based and non-combustion-based technologies can be a complex decision-making process. Both approaches have their advantages and disadvantages, and the selection depends on various factors, such as the specific pollutants being targeted, the characteristics of the emission source and location-specific regulatory requirements. Factors like energy efficiency, operational costs, waste management and the potential for secondary pollutant formation also play a significant role in the decision-making process. In some cases, a combination of technologies may be required (Figure 1).

Combustion-based technologies, such as fluegas desulfurization and selective catalytic reduction, utilize controlled burning to convert pollutants into less harmful substances. Non-combustion-based technologies, including electrostatic precipitators, wet scrubbers and various filtration systems, focus on physical or chemical methods to capture and remove pollutants from the gas stream. The following sections outline some of the most prevalent pollution-control technologies in industry and provide some guidance on their applications.

Non-combustion technologies

As stated previously, non-combustion pollution-control technologies typically will involve a chemical or physical process designed to eliminate polluting species and prevent their associated environmental harm. There are numerous such technologies in use in industry today in a broad range of applications. It is important to note that aerial gaseous streams are not the only source of air pollution — contaminated water and soil can also contribute.

Soil vapor extraction (SVE) systems. SVE systems employ a technique that removes contaminants and hazardous vapors from the soil subsurface. It uses vacuum pressure to pull air through soil that has been saturated with hydrocarbons or volatile organic compounds (VOCs). SVE can be combined with a thermal oxidizer (see below) to further treat any remaining pollutant gases.

Chemical scrubber systems. When chemical scrubber systems are used, there is thorough contact between the gas stream to be treated and water in the presence of a chemical reagent. The treatment capacity of the scrubber depends on the type of waste-gas pollutants found in the process. For instance, if H_2S is found in the waste gas, caustic treatment with an oxidation chemical is required. If NH_3 is found in the waste gas, sulfuric acid with an oxidation chemical is required. If organic com-

FIGURE 1. The selection of the best technology for air-pollution control — or combination of technologies — depends on many factors beyond the pollutant profile, including energy efficiency, secondary pollutant formation and more

pounds with good to moderate water solubility are found in the waste gas, oxidation chemicals, such as hypochlorite or peroxide, are required.

Air stripper systems. Air stripper units are designed to remove hydrocarbons or chlorinated compounds from water. Recovered groundwater is pumped into the top of the system. As contaminated groundwater enters through the top of the air stripper, millions of air bubbles are forced by the blower to pressure up through the perforated trays, vigorously aerating the water to a froth and removing VOCs as gravity pulls the water down through each tray in the stripping column.

Oil-water separator systems. Oil-water separators are designed to accelerate natural separation between water and hydrocarbons. Recovered groundwater is pumped into the first chamber of the system, where small oil droplets contained in the mixture coalesce and form larger droplets that rise to the surface. The large oil droplets are then collected for proper disposal.

Carbon-bed systems. Carbon beds work by physically adsorbing pollutants from the air. Adsorption is a process in which pollutant molecules adhere to the surface of the activated carbon. Although it is evaluated first as a Best Available Control Technology (BACT), carbon-bed technology may not always be the best longterm solution, because carbon replacement and usage can be expensive. There are also safety concerns associated with carbon-bed fires if VOCs cause an exothermic reaction. To reduce such risks, proper air circulation should be included in the design of the bed. Depending on the VOCs, other types of concentrators can be used.

Fabric filters. Also known as baghouses, fabric filters are used for control of particulate matter. These filters consist of numerous fabric bags or tubes through which the gas stream passes. The fabric material captures and retains the particulate matter, allowing the clean gas to pass through. Periodically, the collected particulate matter is removed from the bags using mechanical shaking or pulsing methods. Baghouses are widely employed in industries where high-efficiency dust control is required, including cement manufacturing, metal processing and coal-fired power plants.


Ship & Shore Environmental

FIGURE 2. Regenerative thermal oxidizers (RTOs) enable a very high destruction efficiency for pollutants. There are a variety of RTO configurations that provide different benefits in different applications

Combustion technologies

The majority of combustion-based pollution-control methods fall into the thermal oxidizer category. There are several varieties of thermal oxidizers, but they all are designed to sustain the optimal conditions for oxidation of combustible components of the gas stream. This is done by a careful control of the operating temperature, so that it is sufficiently above the auto-ignition level to provide enough time and excess oxygen to complete the necessary reactions.

Regenerative thermal oxidizer (RTO) systems. RTOs can handle dilute waste gases and achieve a destruction efficiency of 95–99% at operating temperatures of 1,400–1,500°F (Figure 2). Through use of a ceramic heat exchanger, a thermal efficiency of up to 97% can be achieved. Depending on the VOC loading, a specially designed RTO can be used to accommodate higher solvent loading, with a slightly lower thermal efficiency, and use of a hot bypass.

A special poppet-valve design can achieve 99% destruction without use of a puff chamber. The "puff" refers to the small volume of unprocessed air that may remain after RTO treatment. In some applications demanding an extremely high destruction efficiency (above 99%), the "puff" may require re-treatment in a dedicated chamber.

On the same production line, there may be varying exhaust-air volumes, as well as varying solvent mixtures, resulting in high flows and volatile organic compound (VOC) concentrations of up to 25% of the lower explosive level (LEL).

Direct-fired thermal oxidizer (DFTO) systems. DFTOs (Figure 3) are ideal for very high solvent emissions (self-sustaining, with VOC concentrations of up to 50% LEL). They can achieve a destruction efficiency of more than 99%, but normally do not provide any energy recovery. Depending on the solvent loading, this system could be a high energy consumer. However, if periodic vent gas can be optimized and controlled as a continuous flow, thermal oxidation equipment also has heat-recovery options. If vent waste-gas streams have a high heating value to sustain combustion, then thermal oxidation technologies would prove to be a better fit, since the gas streams can be repurposed as fuel gas.

Multi-stage thermal oxidizers. Multi-stage thermal oxidation systems operate more like a standard thermal oxidizer, with sufficient excess oxygen and temperature to destroy the combustibles from the initial stage, while keeping oxygen and

FIGURE 3. In certain direct-fired thermal oxidizers, it is possible to recover heat and potentially use waste streams as fuel gas

temperatures sufficiently low to avoid the reformation of thermal oxides of nitrogen (NOx). A quench media is required to minimize the temperature of subsequent stages, and recycle fluegas (RFG) provides maximum heat recovery.

There are two primary processes for the subsequent stages in a multistaged thermal oxidizer: one process uses two additional stages (for a total of three stages). The initial stage is the reducing stage. A second stage is a quench stage, employing a quench media to cool the initial stage fluegas to about 1,400°F, and a third oxidation stage uses air for final oxidation of the combustibles.

The second process has two stages consisting of the initial reducing stage, employing RFG for quench, and a second oxidizing stage whereby RFG and excess air are combined and injected into the fluegas from the initial stage. The two-stage process is usually an improvement over the three-stage process, because it reduces costs of an extra refractory-lined chamber and simplifies control of the staged process.

Catalytic thermal oxidizers. Catalytic systems dilute waste gases with a destruction efficiency of 95 to 99% at an operating temperature of 700 to 800°F. Thermal efficiencies of 50 to 65% can be achieved with use of a heat exchanger. Catalytic thermal oxidizers can be subject to poisoning, sintering and masking, and the catalyst is often very expensive to replace. This system is not recommended for abating waste-gas emissions.

Recuperative thermal oxidizers. Recuperative systems are suitable for applications with VOC concentrations of 10 to 35% LEL with moderate to high solvent emissions. Recuperative thermal oxidizers can achieve a destruction efficiency of over 99%, and use a shell-and-tube heat exchanger with thermal effectiveness of up to 70%. This system can result in high operating costs if there is a LEL solvent load of less than 15%.

Steam-generating thermal oxidizer (SGTO) systems. SGTO systems are designed so that a standard two-pass firetube boiler with certain modifications can be utilized as an effective air-pollution control system to destroy VOCs. Part of the process emissions are sent through the combustion air blower of the boiler burner. The remainder is passed to the incinerator section at the rear of the boiler. In this manner, the infrared heat released by combustion is utilized in the boiler furnace. Thus, the SGTO is more efficient than the DFTO waste-heat boiler system. It also requires less space.

Selective catalytic reduction (SCR). SCR units are widely used in power plants and industrial facilities to control NOx emissions. SCR systems work by injecting a reducing agent, typically ammonia or urea, into the fluegas stream. As the gas passes over a catalyst, NOx molecules react with the reducing agent, converting them into nitrogen and water vapor, which are less harmful to the environment. SCR systems have shown significant success in reducing NOx emissions and are particularly effective when combined with other pollution-control technologies.

Final thoughts

In conclusion, effective control technologies are crucial for mitigating the adverse effects of air pollution. The selection of combustion-based or non-combustion-based technologies requires careful consideration of numerous factors, and many pollution-control applications may require tailored solutions that align with specific needs and regulatory requirements.

Ultimately, the goal of air-pollution control is to minimize the release of harmful pollutants into the atmosphere, improve air quality and protect human health and the environment. The urgency to address air pollution is amplified by the interconnectedness of environmental challenges, with air pollution exacerbating climate change and vice versa. By reducing air pollution, we not only improve air quality but also contribute to the global effort to combat climate change and create a sustainable and habitable world for future inhabitants. ■

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Proactively Achieving Emissions Reduction

At the outset, tackling emissions-reduction projects to achieve regulatory compliance can seem daunting, but by taking a proactive approach, leaks can be handled before they become a serious emissions issue

Lynnae Psimas and Shalayne Martens
INTEGRA Technologies

IN BRIEF

FOSTERING THE CULTURE

CONTINUOUS BEST PRACTICES

POST-TURNAROUND ACTIVITIES

SEEKING OUTSIDE HELP

To meet global emissions-reduction targets, chemical processing facilities are facing more stringent regulatory requirements across the globe. As emissions regulations become stricter with the rising global focus on environmental impact and worker health, work sites are directly affected in multiple ways. Reduced emissions thresholds and more frequent inspections bring increased focus at a time when the industry is facing labor shortages, decreasing budgets and shrinking timelines. Managing fugitive emissions on top of everything else can feel overwhelming. However, as a part of a facility's ongoing operating approval, effectively managing fugitive emissions is becoming a larger priority. With the right foundation in place throughout an organization, it can be possible to capture and correct leaks before they become regulatory-reportable emissions concerns. Reducing emissions benefits everyone, but it can sometimes seem challenging to implement a proactive program in an economical manner.

Fostering the culture

Effectively managing emissions starts with fostering an environmentally positive work culture, which can be easier said than done. Ensuring that workers understand why they need to support emissions reduction is the first step. Impactful emissions-management programs maintain a strong presence in all branches of a facility, from maintenance to planning to operational safety. This widespread support of emissions management is important, not only to foster positive public perception of the process, but also to protect workers from exposure to dangerous emissions. Planning and execution for emissions-related programs should be communicated clearly and early, with effort to ensure positive buy-in at all levels (Figure 1). This helps to ensure that everyone works toward the same goal — a safe place to work and a facility reputation of clean operational excellence.

While it is certainly important to communicate the value of reducing emissions on a regular basis, simply talking about it is obviously not enough. Workers need documented strategies, with their roles and responsibilities clearly defined — and, crucially, they must be involved in the development of these strategies. Workers at every level must be heard and their perspectives taken into consideration when creating plans to meet emissions-reduction targets. All groups within a facility must work together to find synergies between the environmental requirements and maintenance management. In the new age of remote meetings, it is easier to include more people at the table. Inviting personnel from all departments who can describe the

FIGURE 1. Clear communication of emissions-reduction plans to all plant workers should be done early so that design and operational synergies can be identified

FIGURE 2. During the initial stages of startup following a turnaround, conducting critical leak checks is an effective way to improve regulatory compliance

obstacles they face related to regulatory programs and provide feedback on recommended solutions fosters a culture in which their experiences matter. Furthermore, it guarantees that plans and procedures are created by the people who will implement and be directly affected by those plans. This not only ensures that the plans are practical, but also provides lessons learned and opportunities for improvement, which will help to streamline the program and meet the targets more efficiently.

Continuous best practices

Establishing a workplace culture that is supportive of emissions reduction is fundamental, but it is not sufficient by itself. Workers need realistic solutions to the challenges they face. The following sections compile a list of practices that, when employed within a workplace with a positive emissions-reduction culture, can help to reduce an organization's emissions before they break compliance.

Key functions are required to achieve a quality program. When supported as a regular part of daily operations, the following practices will assist facilities in meeting regulatory targets in a practical manner.

Accurate inventory. Authorities holding jurisdiction look for ways to show noncompliance, which presents economic and reputational implications. Furthermore, there may already be inaccuracies in the way emissions are calculated, because emission factors are often based on old data that may not be comparable to today's more progressive processes. With emissions calculations reliant on source counts and factoring applications, you don't want to calculate sources that are no longer in operation or miss new sources that could put a facility out of compliance.

Therefore, to obtain accurate emissions testing results, you must start with an accurate inventory — and that inventory must be updated continually as processes change. In-scope sources must be accurately represented, and the list of out-of-service equipment should be updated frequently. Establishing a process to routinely assess inventory is imperative and will save time that would be wasted managing redundant or out-of-date records, and will also remedy potential sources of noncompliance.

Internal leak targets. Organizations should set reduction threshold targets with strict rules to capture emissions sources before they become a compliance-driven concern. Leaks that are allowed to continue until they reach significant levels are quite costly, due to additional handling time from both inspection and maintenance requirements. There is a relationship between minor leaks and dangerous events. All such events represent failure in process control. Adequate process control prevents leaks before they happen.

Setting internal targets that provide early indication promotes a proactive approach to correct deficiencies without stringent deadlines. This will establish a total quality-management approach to support future potential derogation. Additionally, as leak thresholds are reduced by regulatory agencies, this approach will support facility confidence in meeting changes in equipment rule commitments.

Maintenance and repair. Ensure craft laborers receive adequate training and are competent in specific types of repair, such as taping, as well as correct procedures and good practices in tightening compression and other threaded fittings. Additional practices that aid in emission management include the following:

- Selecting the proper gasket and utilizing appropriate tightening practices for flanged assemblies
- Applying the proper bolt load based on valve type and service
- Selecting the proper valve based on thermal cycling or frequent use

Training and trade competencies. Another common source of leaks is improper assembly of equipment like compression fittings. Continuous training of all personnel involved in commissioning and startup is essential to ensuring a leak-free startup and preventing emissions before they start.

Post-turnaround activities

Emissions programs often identify an increase in regulatory emission sources for repair following minor or major turnaround activities, despite focused efforts to correct identified emission sources from previous campaigns. This is because facility relaxation and re-pressurization involve many activities that can influence joint integrity. Internal quality checks on focused repairs are a valuable part of any commissioning or startup activity. However, such checks alone are not enough to ensure a fully leak-free startup. While they test the areas that have been broken down, they

FIGURE 3. Workers who have been trained in industry-standard programs bring with them comprehensive expertise in inspection, assembly and disassembly of leakage-prone equipment

neglect other components in an assembly, potentially missing the leaks you aren't looking for. Below are industry good practices that can address additional common sources of emissions increases following commissioning.

Plug placement program. One common source of leaks is the failure to replace valve plugs following turnaround, as well as the inadequate or improper placement of plugs that are replaced. Implementing a plug placement program, in which trained individuals examine equipment to ensure that all plugs have been replaced and tightened correctly, can greatly reduce emissions sources. It is also important to ensure that vent and drain valves are sufficiently closed. Isolations that are not fully closed are another common source of emissions, adding time to maintenance and planning when these issues appear in regulatory campaigns.

Pre-screens. A second important practice to implement following every turnaround is a pre-screen of components to identify any new sources of emissions that may have creeped up from non-focused repair efforts during outage periods. Conducting critical leak checks during the initial stages of startup — specifically after turnaround but before reintroducing feed — can significantly increase positive regulatory-compliance inspection outcomes (Figure 2). This is especially important on equipment that experiences frequent thermal cycling, such as compressors, compression fittings, pump seals, gaskets and plugs.

Seeking outside help

For ongoing leak detection during operations, it can be helpful to find a service provider that can identify leaks during commissioning and startup, keeping operations safe and the environmental impact well within emission regulatory compliance. Such service providers likely have more experience detecting and preventing leaks than general plant personnel, and can streamline the process with specialized skills and technologies to find small leaks, in any service medium, before they become big problems. They can also aid in identifying the repairs that will most support emission reduction and help to design plans to prevent such leaks through engineering analysis and specialized mechanical services.

Another very important preventive measure involves increasing the trade competencies of a site's workers. To assist with this, training measures, such as the American Society of Mechanical Engineers' (ASME; New York, N.Y.; www.asme.org) Bolting Specialist Qualification Program, are advised. This program is designed to train and evaluate a bolter's ability to inspect, assemble, disassemble and tighten bolted joints in accordance with PCC1 standards governing bolted flange-joint assemblies. Such practices will significantly reduce leaks caused by improper assembly of components (Figure 3).

For ongoing leak detection during operations, it can be helpful to partner with a provider of leak-detection and repair (LDAR) equipment and services. Ideally, the technicians you hire should be trained to utilize EPA Method 21 (focused on leaks of volatile organic compounds) and optical gas imaging (OGI) to find leaks quickly and accurately, getting plants back to production more quickly and safely. ■

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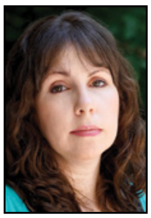

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Keys to Designing Sustainable Production Facilities

Using the food-and-beverage industry as an example, these considerations can help engineers design new facilities with sustainability built in

David Ziskind
NextGen Ag

Rapid population growth and geopolitical tensions continue to keep food security a top priority for nations all over the world. These challenges are compounded by the increasingly visible impacts of climate change, which escalate food-security concerns. In recent years, severe storms, droughts, heat waves and unprecedented cold weather events have had serious impacts on the operations of many commercial and industrial organizations, including food-and-beverage producers. Extreme weather events continue to destroy critical assets and crops around the world, disrupting processes and supply chains.

In response, many companies are prioritizing climate resilience as one of the key methods to reduce business risks. Companies that manage their climate change risks more quickly and thoroughly will be more likely to survive in the coming decades and may also uncover significant competitive advantages. These companies will be better prepared to take advantage of new opportunities in a fast-changing global business environment.

Improving the capacity of assets, buildings and processes to withstand direct harm and disruption from extreme weather is the primary goal of climate resilience. It includes improving overall flexibility and preparation to handle the unpredictability that climate change may bring to supply chains, distribution, costs for goods and commodities, labor, public safety and consumer markets.

Sustainability roadmap

Achieving sustainable food-and-beverage operations starts with determining the objectives, priorities and focus areas. Key sustainability priorities to consider include: energy conservation; water and wastewater management; heating and cooling systems; and zero-emission delivery and industrial vehicles.

Next, screen the shortlisted priorities using a framework, such as a decarbonization roadmap. Decarbonization roadmaps help businesses identify and implement the optimal mix of technologies, low-carbon fuels, advanced processes and recovery systems to meet identified sustainability goals over a specific timeline. For instance, many companies have broadly identified a 30% reduction in greenhouse gas emissions by 2030.

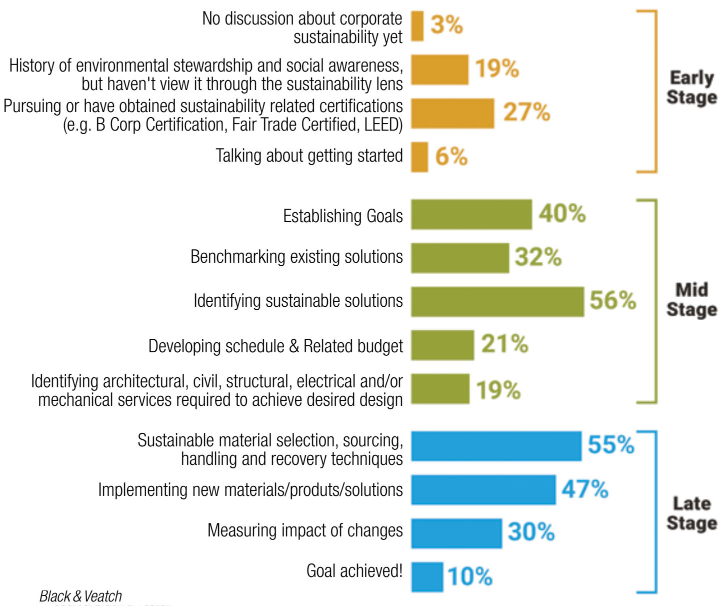
In efforts to scale up production, developing pilot facilities to test climate technology solutions and procedures help to ensure that production at existing manufacturing facilities is not disrupted. Such pilot facilities can help producers examine how their activities interact with surrounding regions, particularly in terms of energy, water and wastewater.

Sustainability by design

Sustainability opportunities can exist even before the design stage and goals can be incorporated into site selection. The site location itself, the logistics or transportation options and the surrounding landscape can all be viewed from a sustainability perspective.

For example, ambient quality, such as air, noise and traffic, can be improved. In terms of transport options, using alternative modes of transportation can be incentivized.

Leveraging the surrounding landscape, stormwater can be managed more efficiently by reducing, controlling and treating stormwater runoff. Vegetated channels can be designed to convey stormwater runoff while removing debris and pollution. Such features also support groundwater recharge. The canopies of heritage trees and wood trellis can help to shield buildings and areas from direct sunrays, making it easier to regulate indoor temperatures. Additionally, rooftop vegetation can



Black & Veatch

FIGURE 1. Responses to a recent survey [*1*] asking the question: Where is your company today in the process of establishing benchmarking, executing and/or achieving your overall corporate sustainability goals?

INTEGRATING PRODUCTION AND SUSTAINABILITY

A recent report,"Integrating Production and Sustainability: How Food & Beverage Companies Can Achieve Net-Zero" [*1*], has found that food-and-beverage companies aim to become more efficient, use less energy and produce less waste or upcycle the waste that has been produced. That said, the report emphasizes that they must see bottom-line results to expand their sustainability programs further.

Most respondents to the poll say they are in mid-to-late-stage planning toward their corporate sustainability goals (Figure 1). The top activities reported were:

- Identifying sustainable solutions (56% of respondents)
- Sustainable material selection, sourcing, handling and recovery techniques (55%)
- Implementing new materials/products/solutions (47%)
- Establishing goals (40%)

The study noted that the understanding of sustainability concepts has matured. For the food-and-beverage industry, upcycling has made processors more aware of the waste they are producing. This awareness is driving the industry to look for opportunities to reduce waste and monetize that waste stream.

Digestion is an area food-and-beverage producers are exploring. Energy recovered from processing wastewater, for example, can be used to reduce operating costs.

The study revealed that processors are often able to implement the basics, including changing out inefficient motors and lighting, adding solar panels on a facility's roof, sealing cracks and replacing insulation. However, companies generally lack the internal skills to ensure the cost-effective application of extensive sustainable practices and technology, such as modifying existing infrastructure, changing out inefficient boiler systems, and conducting energy and water audits. Another example is building water- and wastewater-treatment systems that go beyond simply processing a wastewater stream and sending it to publicly owned treatment works (POTW).

Taking the next step requires finding partners that can identify and implement the optimal mix of technologies, low-carbon fuels, and advanced process and recovery streams. For example, working with architectural and engineering firms with experience in decarbonization, renewable energy and green infrastructure will result in long-term energy and utility cost savings.

Partners who can assist with every step of the sustainability journey are well-positioned to present practical solutions that help food-and-beverage companies reduce their environmental impact and optimize operations. ❐

FIGURE 2. The world's first industrial-scale FeedKind facility in China, designed and built ahead-of-schedule, will produce 20,000 tons of low carbon animal feed annually

provide natural building insulation, with rainwater sustaining the native vegetation and excess water flowing to catchment vessels.

During the preliminary design phase, it is essential to incorporate efforts that reduce energy load, improve efficiency and incorporate the use of renewable energy to optimize energy usage for specific processes. For instance, waste heat can be recovered from heating and refrigeration systems and processing operations and converted into electricity or reused in the food-manufacturing facilities for heating or drying activities.

Optimizing operational and maintenance practices through design can enhance working conditions, boost productivity, lower energy and resource costs, prevent system failures and contribute significantly to achieving these sustainability goals.

From a water-conservation angle, designing the facility to minimize impervious surface cover can reduce runoff and replenish nearby groundwater or aquifers, helping companies reach water-sustainability goals and lower flood risks. Lower water consumption can also be achieved through efficient designs or integrating reuse or recycling processes. Creating stormwater facilities to lessen the building's environmental impact is another key sustainability effort.

Prioritizing the use of integrated and intelligent material can help to maximize building space and material consumption. Using and reusing materials in the most productive and sustainable way across the entire lifecycle is critical. Investing in environmentally preferable materials can reduce the impacts on human health and the environment, and contribute to improved worker safety and health, reduced liabilities and reduced disposal costs.

Waste management during new or retrofitted building construction and demolition can also contribute to sustainability efforts. Effluent management can be more effective when facilities are designed to reduce, repurpose or treat waste streams from solid waste, packaging, wastewater and exhausts.

Food-and-beverage manufacturing processes can be optimized to upcycle waste byproducts into high-value products, such as animal feed, sustainable textile fibers, pharmaceutical and cosmetic items.

Deploying metering systems in buildings can support the monitoring of sustainability measures. That includes decreases in energy and water use, as well as trash production within the building and nearby. Such actionable insights help to refine future sustainability efforts.

Moving forward

With food production accounting for one-third of global greenhouse gas emissions, now is the time for food-and-beverage producers to start achieving long-term goals by

SCALING UP ALTERNATIVE PROTEIN PRODUCTION

With the process for alternative protein manufacturing still evolving (see for example, The Protein Shift, *Chem. Eng.*, April 2023, pp. 12–16) required technologies and equipment will continue to change.

Alternative protein producers will face different challenges at various stages of their commercial journey; these challenges will differ, for example, when getting the processes right at the laboratory stages versus scaling up the process for commercialization.

Finding the right process, utility, equipment and utility infrastructure will be key to maintaining business agility and meeting sustainability commitments. This includes sizing of bioreactors and their potential capacity for the cell culturing process to meet business requirements today and in the future. It also covers optimization of water and energy sustainability efforts.

Prioritizing sustainability

Black & Veatch (B&V) NextGen Ag assisted Aleph Farms, an Israel-based cultivated meat startup, to achieve its goal "to eliminate emissions associated with its meat production by 2025 and reach the same net-zero emissions across its entire supply chain by 2030."

The sustainable food-systems pioneer has committed to net-zero emissions across its supply chain, leveraging existing plans for its pilot plant (BioFarm) to reach sustainability goals at scale.

The partnership leveraged B&V's expertise with sustainable production and process design to build a resilient, compliant and sustainable infrastructure for large-scale production, embracing foundational principles of circular economy and renewable energy.

In Asia, B&V supported the world's first industrial-scale FeedKind facility in China.

FeedKind is an alternative feed ingredient for the aquaculture and animal feed industry produced via natural fermentation that does not use arable land, animal or plant ingredients and uses very little water in its production.

The bio-fermentation facility developed by Calysseo was designed and built ahead-of-schedule by a consortium of B&V and Shanghai LBT Engineering & Technology Co. Ltd. As the consortium leader, B&V provided project management, process design and global procurement expertise.

The facility (Figure 2) — located in the Changshou Economic and Technological Development Area (CETDA), Chongqing Province, China — will produce 20,000 ton/yr of low-carbon animal feed.

breaking down their sustainability goals into individual initiatives that examine risk, cost and the return on that investment.

To scale technology and infrastructure correctly and cost-effectively to feed a growing global population while mitigating geopolitical risks, food-and-beverage producers, including agriculture technology leaders, will need to find partners that have engineering and construction knowledge and expertise to deploy and scale infrastructure efficiently and effectively.

Industry experts help businesses bridge the gap between science, research and development, engineering and commercialization to bring new food-technologies to market, at scale. They provide emerging companies and established manufacturers with end-to-end services from early-stage design and innovation to turnkey facility design. The ideal partner supports clients at every stage of the project lifecycle, from process and development to engineering through the design and construction of a pilot scale or commercial manufacturing facility. ■

Edited by Gerald Ondrey

References

1. Clear Seas Research, BNP Media, 2021, www.bv.com/resources/integrating-production-and-sustainability-how-food-beverage-companies-can-achieve-net.

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Optimization of Inventory Management with Process Integration Using Spreadsheet

A recently developed optimization technique called the automated targeting model is demonstrated for its application on inventory management

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Supply chain management that involves raw material sourcing, product manufacturing and delivery has often been viewed as one of the critical factors for successful business, especially for the manufacturing industry. An important aspect of supply chain management is inventory management, where stock level of raw material or product (or both) could be optimized to ensure maximum profit or minimum cost or losses. In the post-pandemic era, artificial intelligence (AI), automation and digitalization are believed to be the main trends in shaping the future of supply chain management [*1*].

Over the past two decades, several important toolboxes based on *process integration* principles have been developed for supply chain management. In particular, the supply chain composite curve [*2*] is a useful graphical tool that may be used to set a minimum production rate for aggregate planning in stock-level strategy (Figure 1a). The grand composite curve (Figure 1b), on the other hand, allows users to view the inventory level for a production supply chain [*3*]. These graphical tools have the advantages of visual display, which facilitates good discussion and decision making among production personnel. However, they suffer with limitations, such as inaccuracy and tediousness. To overcome the above issues, algebraic targeting tools were also developed [*4*]. Furthermore, the recently developed *automated targeting model* (ATM) is another useful tool to incorporate financial consideration in optimizing supply chain [*5*] and inventory planning [*6, 7*].

In this article, the use of ATM is demonstrated for the optimization of inventory level of maintenance spare parts for a process plant, for a known maintenance schedule.

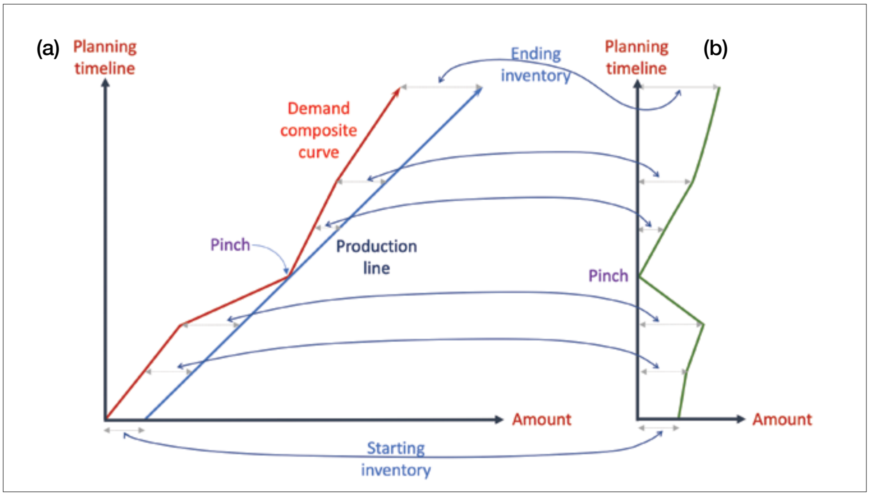

FIGURE 1. Shown here are the supply chain composite curves (a) and the grand composite curve (b)

Automated targeting model

The basic framework of ATM is shown in Table 1. As shown, the time period, t, is listed in Column 1, from earlier to later time period (may be in weeks, months or even years). In Columns 2 and 3, show the demand and supply for each period. Note that the demand values are given, while supply values are to be determined as part of the ATM. Net inventory at the end of t period, I_t, is given in Column 4. In order to maintain a minimum inventory (I_{min}), the actual inventory is to be calculated for each period t in the last column, given as the summation of net and minimum inventory ($I_t + I_{min}$). For more details, see Ref. 4.

The main advantage of ATM is that, its basic form is a linear model, which enable it to be used for inventory planning even using a spreadsheet software, such as Microsoft Excel (with the use of Solver add-in).

Equations (1–3) are the basic formulation of the ATM. The net inventory of each time period $t(I_t)$ is given as the difference between demand, D_t, and supply, S_t, of that period, along with the inventory by from previous period, (I_t – 1), as illustrated by Equation (1). The inventory and supply of all time periods should take non-negative values, shown in Equations (2) and (3).

$$I_t = I_{(t-1)} + S_t - D_t, \text{ for all } t \quad (1)$$

$$I_t \geq 0, \text{ for all } t \quad (2)$$

$$S_t \geq 0, \text{ for all } t \quad (3)$$

The objective function of the model is to minimize the total purchase price, given as in Equation (4).

TABLE 1: BASIC STRUCTURE OF AN ATM

Time Period, t (month/ week)	Demand, D_t (units)	Supply, S_t (units)	Net Inventory, I_t (units)	Actual Inventory, (units)
			I_0	$I_0 + I_{min}$
1	D_1	S_1	I_1	$I_1 + I_{min}$
2	D_2	S_1	I_2	$I_2 + I_{min}$
…	…	…	…	…
t	D_t	S_t	I_t	$I_t + I_{min}$

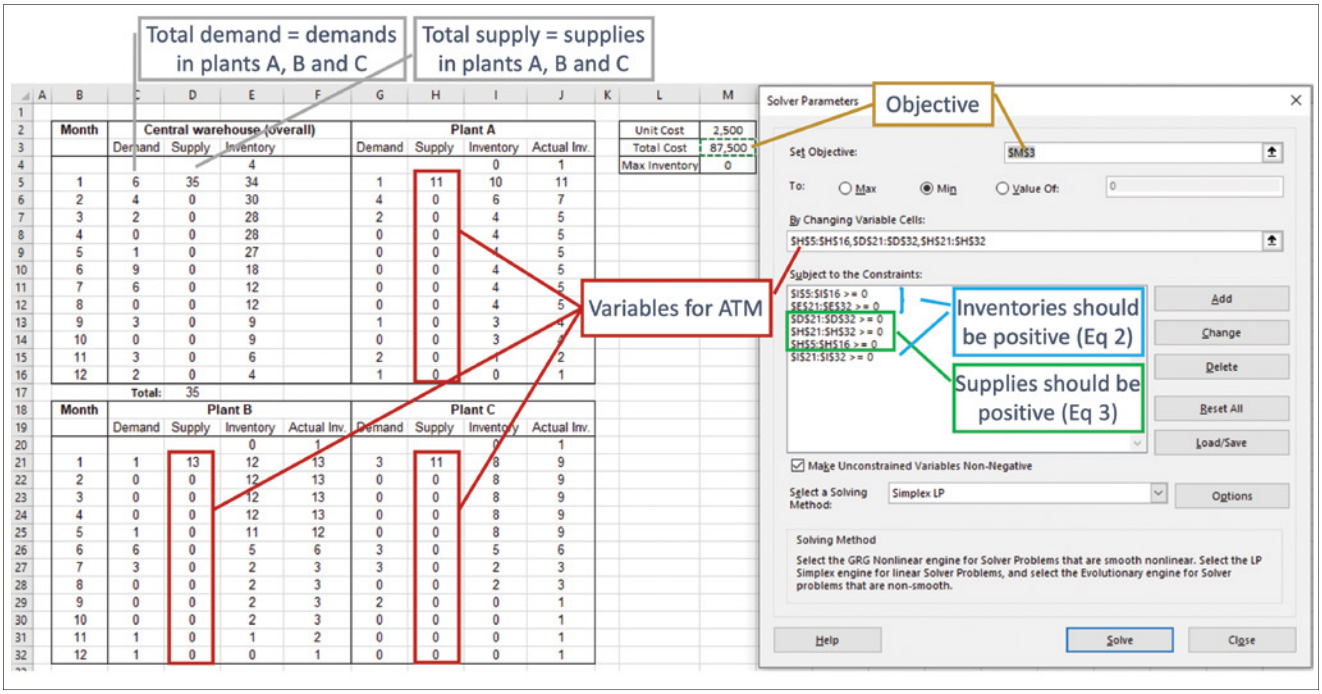

FIGURE 2. This diagram is the spreadsheet setting and results for Scenario 1

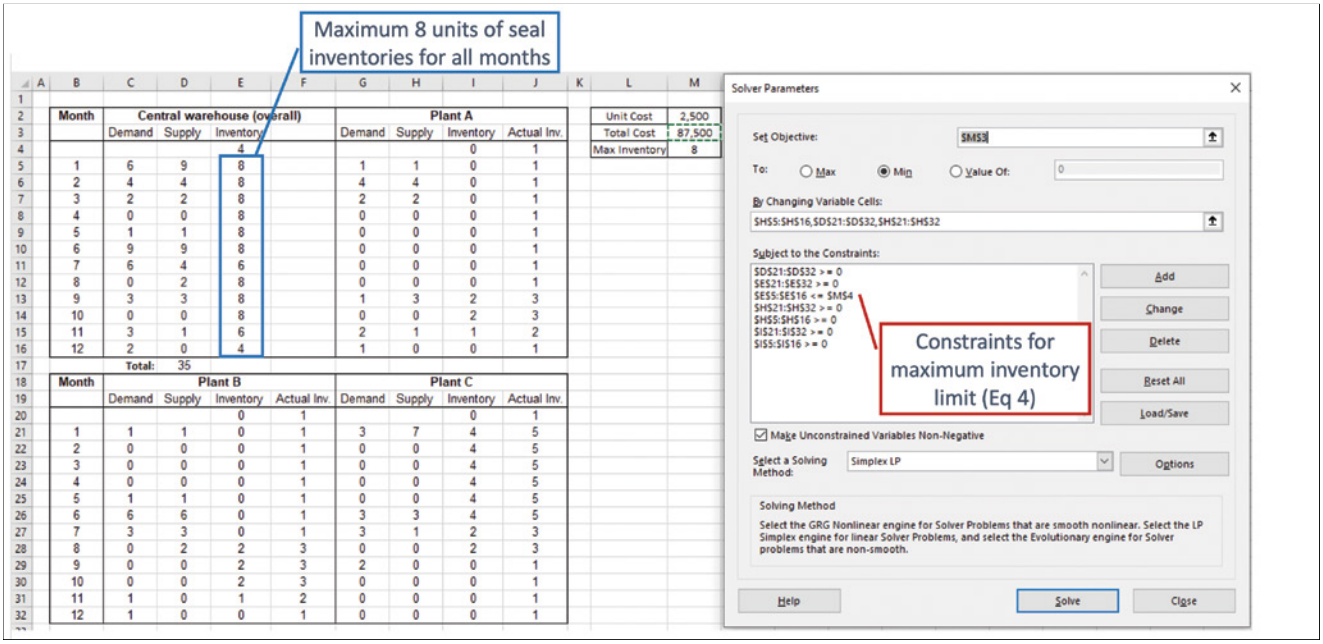

FIGURE 3. This diagram is the spreadsheet setting and results of Scenario 2 — with maximum inventory limit

$$\text{Minimum} = C \sum_t S_t \qquad (4)$$

Where:
C = unit purchase cost

For a given demand across all time period, D_t, the ATM can determine the minimum purchase price, to ensure optimal supplies across all period t, S_t.

An example case

This case study is based on actual data of an operating company in Malaysia. The company has to maintain a large inventory of mechanical seals for the pumps. The replacement of pump seals is necessary after a certain period of operation to ensure good reliability for the pumps. As part of the maintenance schedule, the number of seals to be replaced each month is known.

The company consists of three operating plants and a central warehouse. At any given time, each of the plants and the warehouse must have at least one seal unit to cater for unexpected events. Otherwise, the production schedule may be affected, since some pumps have to be shut off temporarily in any unexpected event. To avoid overstocking of seals, the company sets a maximum limit of eight units across all facilities at any time. This is because the seals would degrade after prolonged storage. Hence, it is unwise to have large inventory for such expensive units (the pump seal costs approximately $2,500 per unit).

Two scenarios are analyzed using the ATM: that is, with and without maximum inventory limit constraint.

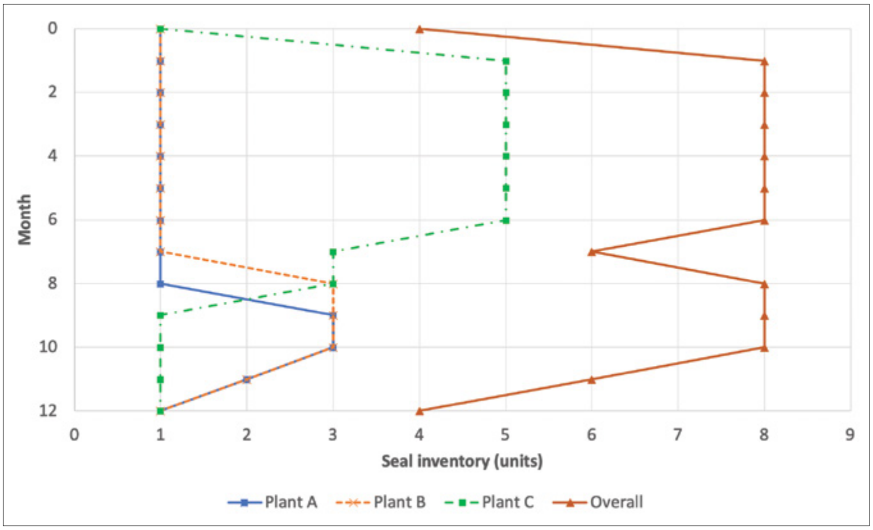

FIGURE 4. Seal inventories in all facilities are displayed in this grand composite curve

Scenario 1: Without maximum inventory constraint. In this scenario, no constraint was set for the maximum inventory units across all facilities. The ATM is solved using MS Excel, the setting and results of Solver are shown in Figure 2. Since the inventories of three plants are to be considered, the ATM is modified such that total demand in Cells C5–C16 in Figure 2 is the total demand of all plants, that is, the sum of Cells G5–G16 (Plant A), C21–C32 (Plant B) and G21–G32 (Plant C). Similarly, Cells D5–D16 (central warehouse) is given as the sum of cells H5–H16 (Plant A), D21–D32 (Plant B) and H21–H32 (Plant C). Besides, these Cells are set as "changing variables" so that they may be varied to meet the demands in individual plants. The objective function is to minimize the total cost (Cell M3). As discussed earlier, constraints are needed to ensure supplies and inventories in Columns D, E, H and I are set to non-negative. Entries with a zero for inventory cells indicate the pinch month of the plant, where the inventory reaches its minimum — that is, one unit (for example, September–December for Plant C).

Figure 2 also shows that solving the ATM resulted a total cost of \$87,500 with 35 pump seals to be purchased in January. These seals will build up the company inventory (see Column E) to cater for demand throughout the year. In other words, all seals are to be purchased in January, so that they may be used in the plants throughout the year.

Scenario 2: With maximum inventory constraint. In the previous scenario, when no constraint is set, the company purchases all necessary pump seals at once in January, in order to meet all demand throughout the year. Although it may be advantageous to buy the units in bulk to enjoy lower purchase and shipping fees, this entails a large financial cash flow for the month of January, as well as requiring a large inventory space. In this scenario, a maximum of eight units is set as a new constraint for every month, given as in Equation 5 (other constraints remain identical).

$$I_t < 8, \text{ for all } t \quad (5)$$

As shown in Figure 3, this new constraint is imposed for the actual inventory (Column E). The results of ATM indicates that a degenerate solution is obtained, with minimum purchase price of \$87,500 that is identical to that in Scenario 1.

Due to the maximum inventory constraint, the model determines that a different number of pump seals will be purchased throughout the year. Doing so leads to a lower inventory of pump seals, and avoids a large cash flow in January, as well as the need for a huge storage space.

To better visualize the inventory levels of all facilities, the *grand composite curves* are plotted and shown in Figure 4.

Concluding remarks

A recently developed optimization technique called the automated targeting model (ATM) was demonstrated for its application in inventory management. It is particularly useful as it may be implemented using a spreadsheet program, such as MicroSoft Excel. Note that the ATM with maximum inventory limit is also useful for material that may encounter quality degradation due to prolonged storage (see Ref. 6, for example). ■

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References

1. Axsom, T., 10 Trends Shaping the Future of Supply Chain Management, www.fictiv.com, 2022, accessed Oct. 2022.
2. Singhvi, A., Shenoy, U. V., Aggregate planning in supply chains by pinch analysis,. *Chem. Eng. Res. Des.* 80, pp. 597–605, 2002.
3. Singhvi, A., Madhavan, K.P., Shenoy, U. V., Pinch analysis for aggregate production planning in supply chains, *Comput. Chem. Eng.,* 28, pp. 993–999, 2004.
4. Foo, D.C.Y., Ooi, M.B.L., Tan, R.R., Tan, J.S., 2008. A heuristic-based algebraic targeting technique for aggregate planning in supply chains, *Comput. Chem. Eng.,* 32, pp. 2217–2232, 2008.
5. Foo, D.C.Y., 2016. Automated targeting model for aggregate planning in production and energy supply chains, *Clean Technol. Environ. Policy* 18, https://doi.org/10.1007/s10098-015-1082-y.
6. Andiappan, V., Foo, D.C.Y., Tan, R.R., Automated targeting for green supply chain planning considering inventory storage losses, production and set-up time, *J. Ind. Prod. Eng.,* 39, pp. 341–352, 2022, https://doi.org/10.1080/21681015.2021.1991015.
7. Chua, X.Y. and Foo, D.C.Y., Optimization of cogeneration system and fuel inventory with automated targeting model, *Clean Technol. Environ. Policy,* 23, pp. 2,369–2,383, 2021, https://doi.org/10.1007/s10098-021-02150-8.

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Real-Time Particle-Size Analysis Technologies: Overview and Case Study

Monitoring particle sizes in real time can improve product quality and reduce costs in chemical processes. Presented here is an overview of available technologies for particle-size analysis and an example involving suspension polymerization

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Effective measurement, in real time, of particle sizes and particle-size distributions in chemical processes can offer potentially significant improvements in process efficiency and reductions in waste and energy consumption. This is true for wet or dry processes handling solid or fluid particles (like droplets or bubbles). A number of technologies available may be able to accomplish this task, including laser diffraction [*1, 2*], photosedimentometry, ultrasound attenuation spectroscopy [*3*], laser backscattering [*4, 5*] and inline microscopy [*6*]. In addition to their differing operating principles, these technologies are often categorized according their measurement position relative to the process — namely offline, at-line, online and inline (Figure 1). Inline measurements are taken directly in the flow of the product, providing real-time feedback on process parameters. Online measurements are similar to inline measurements, but are taken from a separate location that is connected to the process. Online measurements are very often bypass solutions, and there are associated advantages and challenges for such technologies, which are discussed here.

There remains a significant level of confusion over measurement positions of instruments. For example, bypass solutions are still often wrongly considered to be inline technologies. A bypass is a common feature in many process measurement systems, and it can be used to divert a portion of the process flow away from the main line to allow for measurement or analysis. While a bypass can provide a solution when the process is too hot, too cold, or too corrosive for the measurement instrument, it also introduces additional complexity and cost to a process measurement system, and there is a risk of contamination or cross-contamination.

To help improve understanding of the tools available for real-time particle sizing and to clear up confusion over how measurement positions of the devices are considered, this article provides information about the five technologies used for inline particle measurement, and further defines the different possible measurement positions.

To illustrate the use of inline real-time particle sizing, a case study is presented for measuring particle size in the suspension polymerization of expanded polystyrene (EPS). The case study demonstrates how the use of real-time particle sizing in suspension polymerization has proven to be a valuable tool for the improvement of polymer production processes, leading to higher polymer product quality and more efficient and cost-effective processes (Figure 2).

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FIGURE 2. Online measurement of particle size is a key part of the emulsion polymerization process at this plant in Russia

C. Minnich

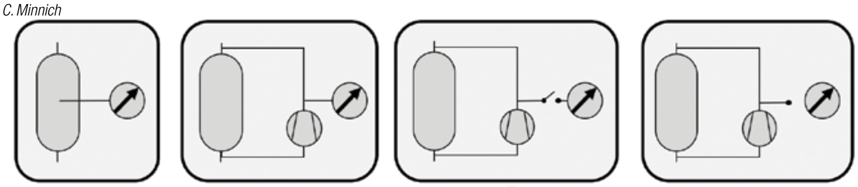

FIGURE 1. The diagrams represent the various measurement-position terminology (adapted from Ref. 9)

Particle sizing technologies

The following sections provide an overview of five technologies used for particle-size measurement: laser diffraction, photosedimentometry, ultrasound attenuation spectroscopy, laser back scattering and inline microscopy.

Despite the clear potential for optimized production processes of, for example, EPS (discussed later), and the availability of several inline particle sizing technologies available for monitoring of EPS particles in production, no industrial "gold" standard has been established in the chemical engineering community. The most reliable technology will depend on several factors, including the specific requirements of the production process, the size of the particles, the operating conditions, and the desired level of accuracy and precision.

Laser diffraction. Laser diffraction (LD) is the most commonly used technology in particle characterization. Here, a light (laser) beam is

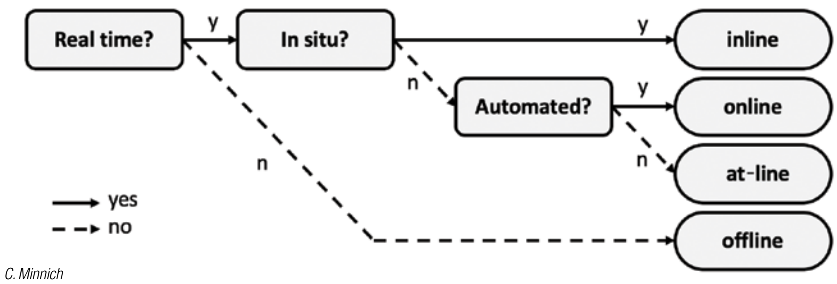

FIGURE 3. The decision tree shown here indicates the selection of measurement position for process analytical technologies (adapted from Ref. 9)

passed through a sample of the particles of interest and their sizes are calculated from the diffraction signal. Specifically, the intensity of scattered light at different angles is measured. Large particles scatter light at smaller angles relative to the laser, while smaller particles scatter light at larger angles.

Applications with high particle concentrations, like in many industrial processes, lead to multiple scattering, which is still not well understood. Therefore, laser diffraction has to be applied in a bypass line (discussed later) if applied to an industrial production processes. Still significant measurement errors were reported using LD in industrial applications. Grumbach and Czermak [7] report that online-applied LD responded differently than the offline system. The bypass or online system was more sensitive to larger particles and predicted a larger particle size and a wider distribution than the laboratory equipment. Constant bias correction worked only as long as the d_{50} remained constant. Especially the error at the edges of the size distribution remained high. Furthermore, the tested bypass systems were more sensitive to process and raw-material variability, so the pre-filtering of data, as well as slope-based bias correction, were necessary to align with the offline system [8]. LD technology is considered a one-dimensional (1D) technology, as it does not provide any information about the shape of the particles.

Photosedimentometry. Photosedimentometry is a technique for measuring the size and distribution of particles in suspensions. It works by shining a light (laser, X-ray or both) through the suspension and measuring the amount of light scattered by the particles. Based on this measurement, the size and distribution of the particles are approximated. The advantages of photosedimentometry are its simplicity and low cost. The instrumentation is relatively simple and does not require specialized training, making it easy to operate and maintain. However, note that photosedimentometry has some significant limitations as well. It provides a very coarse signal, which has to be interpreted by the operator or analysis software. Therefore, the absolute values and their precision are very limited and the system is usually only used as a trending tool rather than a full particle size and shape distribution measurement system.

Ultrasound attenuation spectroscopy. Ultrasound attenuation spectroscopy (UAS) can be used to measure particle-size distribution in colloids, dispersions and emulsions. UAS works by transmitting high-frequency sound waves through the suspension of particles and measuring the attenuation or weakening of the signal as it passes through the suspension. An ultrasonic transducer is placed in the reaction vessel, and a pulse of sound is transmitted through the suspension of particles. The signal received by the transducer is then analyzed to determine the attenuation caused by the particles. From these data, the particle-size distribution can be calculated using mathematical models. In cases where the measurement gap (distance between emitter and sensor) is affected by strong fouling, a bypass solution is often necessary to successfully apply UAS. The UAS technology is considered a 1D technology, because it does not provide any information about the shape of the particles.

Laser backscattering. Laser backscattering (LBS) technology works by emitting a focused laser beam into the reaction vessel and measuring the backscattered light as particles pass through the beam. As particles pass through the beam, they scatter the light, creating a unique signal that can be analyzed to determine the chord length distribution. The probes can usually be easily placed in the reaction vessel using a standard flange. The challenge is to correctly differentiate background scattering signals from any specific particle signal, and then to interpret the chord length into a particle size. As the laser beam might interact only with a short edge of the particle, the chord length distributions are usually undersizing the actual particle-size distribution. LBS technology is also considered a 1D technology, as it does not provide any information about particle shape.

Inline microscopy. The last discussed technology in this article are process implementations based on inline microscopy (IM), coupled with automated image analysis. Inline microscopy allows for the real-time monitoring of particle size and shape during the production process. This enables operators to make adjustments to reaction conditions in real time, which helps to ensure consistent product quality. The technology nowadays usually comes with cameras ready for high-resolution images. On these, individual particles are identified and evaluated as oversized particles, agglomerates, or

FIGURE 4. Real-time particle sizing has become a crucial tool in the polymer industry because of its numerous advantages, including better control of the polymerization process

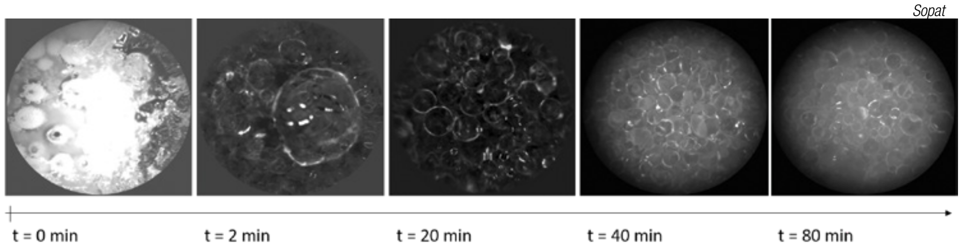

FIGURE 5. As the expanded polystyrene polymerization reaction progresses (left to right), monomer is consumed and the polymer particles grow in size

other unwanted characteristics that may impact product quality. In addition to size measurements, inline microscopy can provide detailed information on the shape of the particles, which can be useful in understanding how the particles will behave during downstream processing.

As with all inline technologies, inline microscopy eliminates the need for manual sampling and analysis, which reduces the potential for sampling errors and ensures that the data collected are representative of the entire reaction mixture. In many applications, the rotational movement of the individual particles in the process stream, combined with high speed imaging, the IM technology is considered a "2.5D" technology, as it does provide shape information from different angles of the particles, as well as their sizes in different dimensions.

Measurement position

Standardization and clear communication in process measurement location and analysis is important to avoid ambiguity and confusion. In the context of process measurement and analysis, a measurement position refers to a specific point or location where the measurement is taken relative to the process. This can be an exact physical location in a process pipeline or vessel, or even a virtual location in a computer simulation or model.

The different use of the classification inline, online, at-line, and offline in the process analytical technology (PAT) and automation communities regularly causes ambiguity in communication. There can be some overlap among them, and the terms are used inconsistently across different industries or applications. Therefore, the available definitions of the classifications are summarized and merged in several recent studies [*8*]. An updated nomenclature targeting the intended function of the analyzer rather than its features was suggested by Minnich [*9*]. Figure 1 shows schematic diagrams from Ref. 9.

However, in general, they are used to describe the timing and location of process measurements and are defined as follows:

Inline. Inline measurements are taken while the process is running, directly in the flow of the product being measured. Inline measurement devices are installed in pipes or other process equipment and provide real-time feedback on process parameters, such as temperature, pressure, or flowrate.

FIGURE 6. Engineers can adjust reaction conditions in real time to ensure the desired product quality and yield

Online. Online measurements are similar to inline measurements in that they are taken while the process is running, but they are typically taken from a separate location that is connected to the process. For example, an online pH sensor might be installed in a tank or vessel that is part of a chemical process, but not directly in the flow of the product being measured.

At-line. At-line measurements are taken at a sampling point in the process, but not necessarily while the process is running. The sample may be collected and transported to a laboratory for analysis, or it may be analyzed on-site using portable instruments or benchtop equipment. At-line measurements are useful when inline or online measurements are not feasible or practical.

Offline. Offline measurements are taken outside of the process, typically in a laboratory or other dedicated analysis area. Samples are collected and transported to the analysis location for testing. Offline measurements are often used for quality control and troubleshooting purposes.

Bypass technologies

A bypass line is a common feature in many process-measurement systems, and it can be used to divert a portion of the process flow away from the main line to allow for measurement or analysis. A setup like this is recommended in terms of process control to prevent a shutdown or lost product if analyzers require frequent cleaning, calibration or validation.

A bypass might be an option when the process media is too hot, too cold or too corrosive for the measurement instrument. In some cases, the process conditions may be too harsh for the measurement instrument, and a bypass can be used to divert a portion of the flow to a separate location where the instrument can be safely installed and protected. On one hand, there are some essential benefits of using a bypass, such as the following measurement situations:

If the measurement requires a long or complex flow path. Some measurement techniques require a long or complex flow path to achieve accurate results. A bypass can be used to provide the necessary flow path without affecting the main process flow.

If the instrument requires frequent maintenance or calibration. A bypass can be used to iso-

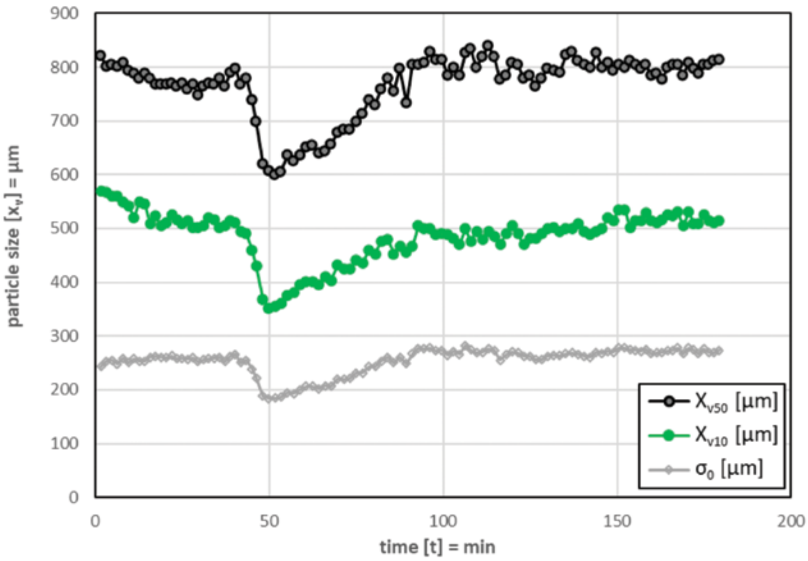

FIGURE 7. The graph shows particle size changes over time

late the instrument from the main process flow, making it easier to access and maintain.

When the process flow is intermittent. In some processes, the flow may be intermittent or variable, which can make it difficult to take accurate measurements. A bypass can be used to divert a constant flowrate to the measurement instrument, ensuring that measurements are taken consistently.

On the other hand, there are some clear disadvantages of using a bypass for the measurements, including the following:

Delayed response time. The bypass diverts a portion of the process flow away from the main line. When this occurs, there will be a delay in the response time of the measurement system. This can result in slower or less accurate measurements, especially in processes where rapid changes in flowrate or process conditions are common.

Increased complexity and costs. Adding a bypass to a process-measurement system will add additional components, such as valves, pumps, flowmeters and tubing. These components will increase the complexity and cost of the system. This also increases maintenance and makes troubleshooting more difficult and expensive.

Increased risk of contamination. Depending on the process and the materials being measured, using a bypass can increase the risk of contamination or cross-contamination. This can affect the accuracy and reliability of the measurements and can also pose a safety risk.

Reduced flowrate. Diverting a portion of the process flow away from the main line can reduce the overall flowrate, which can have an impact on the efficiency and throughput of the process, if the product cannot be reverted into the main product stream. That would also lead to product loss.

It is worth noting that using a bypass introduces additional complexity and cost to a process measurement system, so it is important to carefully evaluate the benefits and drawbacks of using a bypass for your specific application. In general, a bypass should be used when it is necessary to achieve accurate and reliable measurements under challenging process conditions and no real inline technologies are available for this measurement task. Therefore, the definition of "real inline" technologies is given below based on existing ISO standards and literature.

Decision tree

A clear procedure of classifying an analyzer according to measurement position is suggested by Minnich [*9*]. The decision tree (Figure 3) is based on the critical categories of real-time (yes or no), in situ (yes or no) and automating capabilities.

Based on this clear decision tree, bypass solutions are not considered inline. Available in situ technologies, which are able to be applied in an industrial environment, such as suspension polymerization production (high temperature, high pressure, explosive atmospheres) are only available for ultrasound attenuation spectroscopy, laser backscattering and inline microscopy.

Particle sizing in polymerization

Real-time particle sizing in suspension polymerization has become a crucial tool in the polymer industry due to its numerous advantages [*10*] (Figure 4). First, real-time monitoring of particle size and distribution enables better control and optimization of the polymerization process, leading to improved polymer quality and increased productivity and reduced waste. This can result in higher output and a reduction in waste, leading to cost savings. Second, the ability to monitor and control particle size and distribution during downstream processing can also result in more consistent and higher-quality polymer products. This can lead to increased end-user satisfaction, which can result in higher sales and greater profits. Finally, real-time particle sizing provides detailed information about the polymerization kinetics, including the nucleation, growth, and

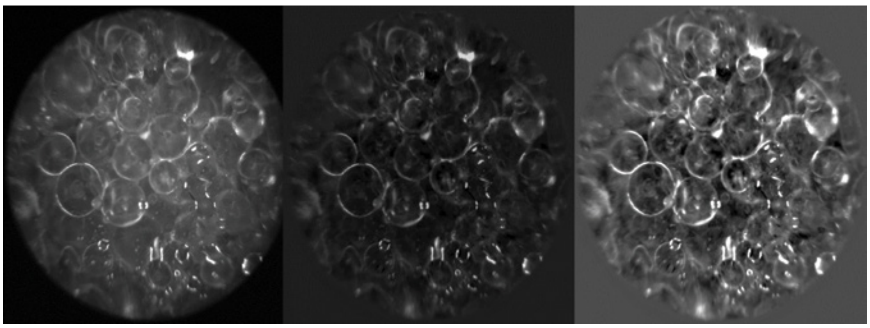

FIGURE 8. The images captured by the camera are processed digitally to remove background noise or distortion, and to enhance the features of the particles

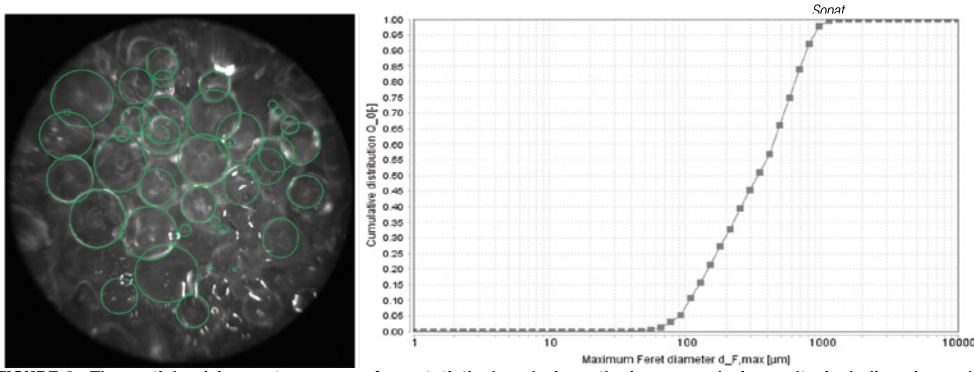

FIGURE 9. **The particle-sizing system can perform statistical analysis on the image-analysis results, including size and shape data, to provide detailed information about the particle population, such as the mean particle size and particle-size distribution**

coagulation stages, enabling a more in-depth understanding of the reaction mechanisms.

The detailed information provided by inline particle sizing instruments can be used to develop new and improved polymerization methods, leading to the production of novel materials with unique properties. This can result in the development of new market opportunities and increased revenue.

Overall, the use of real-time particle sizing in suspension polymerization has proven to be a valuable tool for the improvement of polymer production processes, leading to higher quality, more efficient, and cost-effective polymer products. The driving force for the implementation of inline particle sizing instruments is due to its potential for opening significant financial end ecological benefits for any polymer plant.

EPS production example

An example for the evaluation, selection and deployment of a real-time particle sizing analysis system can be found in the case of a real plant installation in one of the largest EPS plants in Europe. The Russian petrochemical company SIBUR (Moscow, Russia; www.sibur.com) has a plant in Perm, Russia, where EPS is produced.

At that plant, a cylindrical batch vessel is used for suspension polymerization. It consists of a three-blade agitator and a heating jacket, and it can be operated at up to 40 bars. The total volume is 20,000 L. The agitator in the vessel is used to disperse the monomer as droplets into the aqueous phase and keep the droplets, which later react to polymer particles, suspended throughout the whole process. A dipping pipe was used to mount the inline analyzer from the top, through a DN350 flange in the lid of each of the two vessels.

After the batch vessel is pressurized and filled, the stirrer creates and then permanently distributes monomer droplets. The droplets become smaller due to the high energy input through the stirrer. Stabilizers are added to the dispersion to hinder coalescence phenomena, which together with the stirring, leads to a clear size decrease of the droplets over time. Through the agitation, the monomer comes into contact with the initiator, which triggers the polymerization reaction. As the polymerization reaction progresses, the monomer is consumed, and the polymer particles grow in size. The process can be seen from the inline images in Figure 5.

The stirring rate and impeller design affect the hydrodynamics within the reactor and, therefore, the particle-size distribution. If the stirring rate is too low, the monomer droplets may not be dispersed adequately, leading to poor reaction kinetics and the formation of oversized particles. Conversely, if the stirring rate is too high, the monomer droplets may be broken up too much, leading to a strong decrease in the average particle size.

In addition to stirring, other factors, such as the concentration of the monomer, the type and concentration of the initiator, and the reaction temperature, can also influence the reaction kinetics and the resulting particle size distribution. Real-time monitoring of the particle-size distribution using inline particle-sizing techniques was used to optimize these parameters and ensure the desired product quality and yield (Figure 6). The results for 10 (X_{v10}) and 50 (X_{v50}) volume percent median of the particle-size distribution are shown in Figure 7, together with the number based standard deviation of the particle-size distribution.

After 10 minutes, the three values follow the same trend. The first 10 minutes are still very affected by the filling procedure and therefore, are likely to be influenced by irregularities. So it does take some time until both phases are mixed with each other. The lighter phase is creaming up and only slowly pulled into the bulk dispersion, resulting in lower monomer concentration in the beginning, leading to a narrower size distribution. Furthermore, some of the early monomer droplets might be significantly larger than the field of view of the used system. However, the initial stage is overcome after 10 minutes of mixing where fully dispersed condition is achieved. In the first 40 minutes of the process, the monomer is mixed into the aqueous phase, the droplets are created and get stabilized by surface active agents.

After 40 minutes, the initiator is fed into the process. This again has a significant impact on the interfacial tension of the monomer against the aqueous phase. The interfacial tension is decreased and while the agitation stays constant, the droplets are broken up more rapidly and the size for the X_{v50} decreases from 800 to 600 µm. However, right after this intense mixing step, the polymerization reaction starts, turning the monomer droplets into solid polymer particles over time. The size of the polymer particles increases as the monomer is consumed and more polymer is formed. The rate of particle growth may also change as the polymer concentration increases and the particle surface area decreases, leading to reduced mass transfer rates. The growth process is roughly finished after 100 minutes. The mixing is continued for another 80 minutes. As the polymerization

FIGURE 10. Production lines with inline particle-size monitoring can increase process stability and product quality

takes place from the shell to the core of the particle, the mixing time needs to be long enough for the particles to fully polymerize.

By measuring the particle-size distribution over time, it is possible to track changes in the reaction kinetics and identify any issues that may arise during the process, such as agglomeration or the formation of oversized particles (Figure 8). This information can be used to adjust the reaction conditions in real time to ensure the desired product quality and yield.

Image analysis

Due to the high optimization potential and significant possible savings, the SIBUR plant in Perm was upgraded with two automated inline analyzers for their two main production vessels of EPS. The inline microscopes, coupled with an automated image-analysis system, was installed to gain information about particle shape and size. Based on the inline results, the quality of the EPS is monitored, and agitation speed and chemical component feeding are optimized (Figure 9).

The drop and particle size and their distributions are monitored with an inline imaging system. The system uses a combination of high-speed imaging and digital image analysis to capture and analyze images of particles in the process. The images are analyzed using proprietary image analysis software that can determine the size, shape and other properties of each particle. The software can also differentiate between different particle types, which eliminates the misreading of bubbles as monomer droplets or polymer particles.

The image-analysis system that was used includes digital image processing. The images captured by the camera are processed digitally to remove any background noise or distortion, and to enhance the features of the particles. A software system uses pattern-recognition algorithms to identify particles and differentiates between different types of particles, based on their size, shape and other properties [*11*].

The system can use machine learning algorithms to learn and adapt to new types of particles, allowing it to accurately identify and analyze particles even in complex or changing environments [*12*]. It can also perform statistical analysis on the size and shape data to provide detailed information about the particle population, such as the mean particle size and particle-size distribution.

By using these advanced image analysis techniques, the installed system provides highly accurate and detailed information about the monomer droplets, as well as the polymer particles in real-time throughout a full polymerization process (Figure 10). The real-time monitoring led to a significant increase in process stability and product quality, reducing waste through thoughtful process optimization based on the real-time data by 28% throughout the fourth quarter in the production year 2021. ■

Edited by Scott Jenkins

References

1. Davis, C.R., Kelly, S.L. and Erk, K.A. Comparing Laser Diffraction and Optical Microscopy for Characterizing Superabsorbent Polymer Particle Morphology, Size, and Swelling Capacity. *Journal of Applied Polymer Science*, 135 (14), 46055, 2018. https://doi.org/10.1002/app.46055.
2. Li, H., Li, J., Bodycomb, J. and Patience, G. S. Experimental Methods in Chemical Engineering: Particle Size Distribution by Laser Diffraction-PSD. *The Canadian Journal of Chemical Engineering* 2019, 97 (7), 1974–1981. https://doi.org/10.1002/cjce.23480.
3. Boscher, V., Helleboid, R., Lasuye, T., Stasik, B. and Riess, G. On-Line Acoustic Attenuation Spectroscopy of Emulsions Stabilized by Vinyl Alcohol-Vinyl Acetate Copolymers: A Model System for the Suspension Polymerization of Vinyl Chloride. *Polymer International*, 58 (10), 1209–1216, 2009.
4. Hukkanen, E. J. and Braatz, R.D. Measurement of Particle Size Distribution in Suspension Polymerization Using in Situ Laser Backscattering. *Sensors and Actuators B-Chemical*, 96 (1–2), 451–459, 2003.
5. Xie, G., Pan, P. and Bao, Y. Online Monitoring of Drop/Particle Size and Size Distribution in Liquid–Liquid Dispersions and Suspension Polymerizations by Optical Reflectance Measurements. *Journal of Applied Polymer Science*, 133 (30) 2016. https://doi.org/10.1002/app.43632.
6. Cocke, J. and Maass, S. Cross Linking Between the Baffling Effect and Phase Inversion During Liquid–Liquid Monomer Mixing. *Macromolecular Reaction Engineering*, 11 (4), 1700015-n/a, 2017. https://doi.org/10.1002/mren.201700015.
7. Grumbach, C. and Czermak, P. Process Analytical Technology for the Production of Parenteral Lipid Emulsions According to Good Manufacturing Practices. *Processes*, 10 (6), 2022. https://doi.org/10.3390/pr10061174.
8. Emmerich, J., Tang, Q., Wang, Y., Neubauer, P., Junne, S. and Maass, S. Optical Inline Analysis and Monitoring of Particle Size and Shape Distributions for Multiple Applications: Scientific and Industrial Relevance. *Chinese Journal of Chemical Engineering*, 27 (2), 257–277, 2019. https://doi.org/10.1016/j.cjche.2018.11.011.
9. Minnich, C., Hardy, S. and Krämer, S. Stopping the Babylonian Confusion: An Updated Nomenclature for Process Analyzers in PAT Applications. *Chemie Ingenieur Technik*, 88(6), 694–697, 2016. https://doi.org/10.1002/cite.201500188.
10. Richards, J. R. and Congalidis, J. P. Measurement and Control of Polymerization Reactors. *Computers & Chemical Engineering*, 30 (10–12), 1,447–1,463, 2006.
11. Maass, S., Rojahn, J., Hänsch, R. and Kraume, M. Automated Drop Detection Using Image Analysis for Online Particle Size Monitoring in Multiphase Systems. *Computers & Chemical Engineering*, 45, 27–37, 2012. https://doi.org/10.1016/j.compchemeng.2012.05.014.
12. Panckow, R. P., McHardy, C., Rudolph, A., Muthig, M., Kostova, J., Wegener, M. and Rauh, C. Characterization of Fast-Growing Foams in Bottling Processes by Endoscopic Imaging and Convolutional Neural Networks. *Journal of Food Engineering*, 289, 110151, 2021. https://doi.org/10.1016/j.jfoodeng.2020.110151.

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Changes to Calculation Inputs for CEPCI Due to Discontinued Data Series

Discontinued series IDs associated with producer prices for storage tanks requires a modification to the CEPCI

Scott Jenkins
Chemical Engineering

The *Chemical Engineering* Plant Cost Index (CEPCI) is a widely used tool for comparing plant construction costs in the chemical process industries (CPI) between different time periods since 1963. Over its history, the underlying details of the index have been revised and adjusted several times. For discussions of those changes, see Refs. 1 and 2.

The source data on which the CEPCI is calculated, namely producer price index (PPI) data, come from information collected and published by the U.S. Bureau of Labor Statistics (BLS; Washington, D.C.; www.bls.gov), which is a part of the U.S. Department of Labor. For more information on the collection and reporting of producer price indices, see the box on p. 44.

Periodically, the BLS makes changes to the data that they collect and report, some of which necessitate changes in how the CEPCI is calculated. For additional background on how the CEPCI is calculated, see the box at the right of this page.

One such change is reflected in this month's CEPCI data, which can be found on p. 48. The change revolves around data on industrial storage tanks and pressure vessels, and is discussed in this article.

Storage tank series IDs

Storage tanks and pressure vessels are important components of many CPI plants and are included in many capital construction projects at plant sites. The CEPCI has traditionally included several inputs from PPIs having to do with tanks and vessels, including storage tanks of different sizes (at ambient pressure), pressure tanks and vessels, and metal tanks and vessels that have been custom-fabricated at a factory and field-erected. In the past, these multiple categories have been assigned an identifying code, according to the North American Industry Classification System (NAICS), administered by the U.S. Census Bureau (Washington, D.C.; www.census.gov/naics). The NAICS code categories are used by the BLS, and correspond to the series IDs for each of PPIs published by BLS. The codes are arranged first by broader categories of equipment, then subdivided by increasing levels of detail for different types of equipment within the broader categories.

In the case of storage tanks and vessels, a broad category for "metal tanks," given the PPI Series ID code WPU107201, is made up of seven more detailed indexes that comprise the broad category (Table 1). Ac-

TABLE 1: CATEGORIES OF TANKS AND VESSELS ALONG WITH THEIR CORRESPONDING NAICS CODES

10720104	Storage and other non-pressure tanks
10720122	Gas cylinders
10720126	Metal tanks, complete at factory, standard line pressure
10720135	Metal tanks and vessels, custom fabricated at factory, field erected
107201351	Ferrous metal pressure tanks and vessels (more than 24-in. diameter and 5-ft^3 capacity)
107201352	All other metal tanks and vessels, custom fabricated at the factory
10720152	Metal tanks and vessels, custom fabricated and field erected

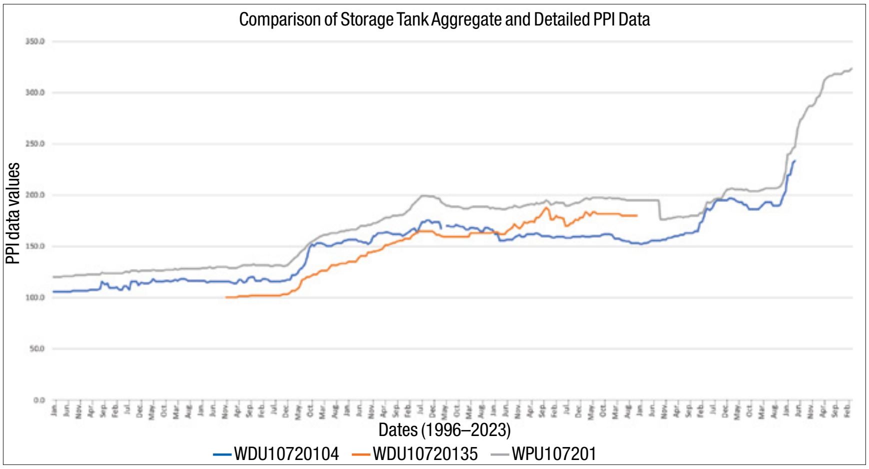

FIGURE 1. The PPI data series that aggregates different categories of storage tanks has historically followed a similar general trajectory to the individual PPI series IDs that comprise it

INFORMATION ON THE CEPCI

The CE Plant Cost Index is actually a composite that consists of four subindices. The headings of these components are the following: Equipment; Construction Labor; Buildings; and Engineering and Supervision (see Table 2). The Equipment subindex is itself a composite of seven other indices, each focusing on a particular category of process equipment. The component indexes are compiled, and weighting factors are applied to make up the Equipment subindex. The three other subindexes are compiled independently from appropriate inputs. Information on these four indexes has been reported running back to 1947. After weighting and normalizing the values, the four sub-indexes are combined to constitute the CEPCI. For each year in the past, an annual value for the CEPCI is calculated based on the arithmetic mean of 12 monthly values for a given year. CEPCI data from previous years can be found at the following URL: www.chemengonline.com/pci. ❏

PRODUCER PRICE INDICES

BLS is a U.S. federal agency that measures labor-market activity, working conditions and price changes in all sectors of the economy. It collects and analyzes many types of economic information to assist decision-making in the public and private sectors. One set of data published by the BLS is the producer price indexes (PPIs). As the BLS defines them, producer price indexes "track the average change in net transaction prices that domestic producers in the mining, manufacturing, agriculture and forestry sectors, as well as certain service industries, receive for the products they make and sell." To construct the PPIs that it reports, BLS conducts voluntary, confidential, respondent-based surveys each month to collect information from manufacturers about costs. BLS economists and analysts review a statistically chosen representative sample of price quotations in business transactions to build the PPIs. Overall, there are around 10,000 PPIs covering more than 500 industries.

In order to publish values for PPIs, the data collected by the agency must meet certain criteria. In its normal operations, BLS reports that some respondents will fail to provide information to them. In cases where a particular index lacks adequate response for a given month, BLS will withhold publication for that index in that month. In that case, the best available data are from the most recently published value of that particular PPI. It can be the case that data are not published for a particular PPI for several months at a time. If, at a later time, the criteria for publication for a PPI are once again met, the BLS will resume publishing data for that PPI.

A carefully selected group of 41 PPIs is used as raw input to the CEPCI. The set represents a diverse set of materials and components that go into the construction of a CPI facility, including steel products, concrete pipe, tanks, fans, piping and many others. In addition, the CEPCI uses 12 labor-cost indexes, which are also compiled by BLS. Relevant PPI information reported by the BLS is collected by *Chemical Engineering* editors and used to calculate the monthly change to the CEPCI. ❑

cording to BLS, the detailed indexes under code 107201 "could not be supported individually, so they were deleted." To follow production in this area, "data users now must use the higher-level code that rolls the detail into a single, grouped index," BLS says. Generally, within a set of PPIs, the nearest available substitute for a discontinued or unpublished index is the next higher level of aggregation, explains BLS PPI economist Joseph Kowal. Therefore, the nearest available substitute for unpublished eight-digit detailed indexes would be the corresponding broader six-digit aggregate indexes (next higher level of aggregation).

It should be noted that all the detailed information within the set of PPI Series ID codes beginning with "1072" was, and remains, product manufactured from heavy-gauge metal, BLS' Kowal says.

How CEPCI adjusts

Going forward, the CEPCI will track the broader "metal tanks" PPI series ID as a substitute for two individual, more specific PPI Series IDs that had been included in the CEPCI in the past. Because the broader category of metal storage tanks now being tracked is an aggregation and combination of the more specific former Series IDs for different types of tanks, there is good reason to believe that future increases or decreases in the producer prices for these assets will be reflected in the data for the PPI Series ID for metal tanks.

The graph shown in Figure 1 compares PPI values for metal tanks over time to some of the values for the specific categories from the past. The PPI series ID for the aggregated tank data is shown alongside two of the more specific storage-tank categories — namely those for metal storage tanks and non-pressure vessels (WPU10720104) and for custom-made vessels and tanks that are factory-made and field-erected (WPU10720135). Although the behavior of the producer-price data do not overlap completely, the overall trends are generally similar. By tracking the aggregate tank PPI series ID, the CEPCI can take into account the contributions that various types of metal storage tanks and pressure vessels make to construction costs of capital projects.

To maintain the continuity of the CEPCI and keep the number values from the future tracking of the "all metals tanks" category in line with the formerly published numbers, we will be calculating a percent change for the new series ID and applying that percent change (positive or negative) to the last available numbers obtained for the (now discontinued) series IDs. This will result in a new value that reflects the change in the PPI for storage tanks, but that also maintains the continuity of the historical PPI values.

TABLE 2. CEPCI SUBINDEXES COMPRISING THE CE PLANT COST INDEX (COMPOSITE)

Equipment subindex
• Heat exchangers and tanks
• Process machinery
• Pipes, valves and fittings
• Process instruments
• Pumps and compressors
• Electrical equipment
• Structural supports and miscellaneous
Construction Labor subindex
Buildings subindex
Engineering and supervision

Over time, this process of updating the inputs to the CEPCI based on available data from the BLS will improve the accuracy and timeliness of the CEPCI subindexes as well as the overall CEPCI.

The *CE* editorial team will continue to monitor the data available from BLS for calculation of the CEPCI and will report any additional changes required in the future. ■

Acknowledgements

The author would like to thank Joseph Kowal, an economist with the BLS Producer Price Index Program, for the extremely helpful information on PPIs he provided as this article was being developed.

References

1. Jenkins, S., The *CE* Plant Cost Index: An Update, *Chem. Eng.*, April 2018, pp. 76–77.
2. Vatavuk, W.M., Updating the *CE* Plant Cost Index, *Chem. Eng.*, January 2002, pp. 62–70.
3. Ulrich, G.D. and Vasudevan, P.T., Capital Costs Quickly Calculated, *Chem. Eng.*, April 2009, pp. 46–52.
4. United States Census Bureau, North American Industry Classification System (NAICS), www.census.gov/naics.
5. United States Bureau of Labor Statistics, Handbook of Methods, BLS Office of Publications and Special Studies, www.bls.gov/opub.
6. United States Bureau of Labor Statistics, Producer Price Index Program, www.bls.gov/ppi.

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Economic Indicators

2021 2022 2023

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CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957–59 = 100)	Apr. '23 Prelim.	Mar. '23 Final	Apr. '22 Final
CE Index	803.4	799.1	816.3
Equipment	1,014.5	1,008.5	1,037.1
Heat exchangers & tanks	832.9	821.1	876.0
Process machinery	1,041.8	1,032.9	1,063.9
Pipe, valves & fittings	1,397.6	1,401.7	1,472.8
Process instruments	567.2	566.4	573.5
Pumps & compressors	1,391.9	1,391.8	1,248.9
Electrical equipment	796.0	794.8	751.8
Structural supports & misc.	1,128.5	1,119.5	1,144.7
Construction labor	362.5	361.7	348.3
Buildings	808.3	805.4	827.0
Engineering & supervision	313.8	313.0	311.8

Annual Index:

2015 = 556.8

2016 = 541.7

2017 = 567.5

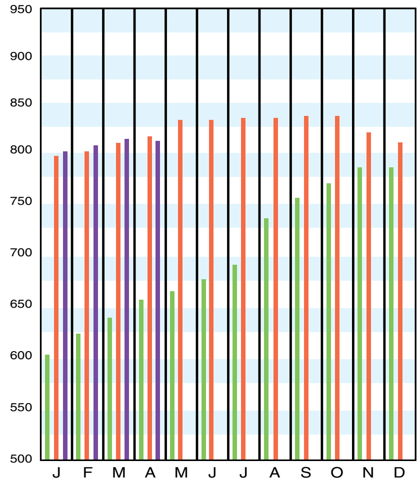
2018 = 603.1

2019 = 607.5

2020 = 596.2

2021 = 708.8

2022 = 816.0



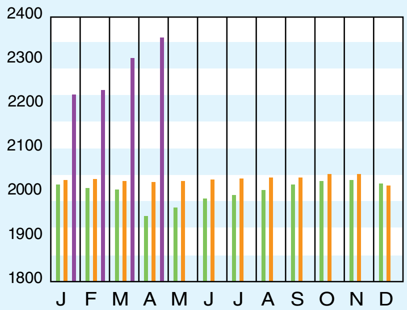
Starting in April 2007, several data series for labor and compressors were converted to accommodate series IDs discontinued by the U.S. Bureau of Labor Statistics (BLS). Starting in March 2018, the data series for chemical industry special machinery was replaced because the series was discontinued by BLS (see *Chem. Eng.*, April 2018, p. 76–77.)

CURRENT BUSINESS INDICATORS

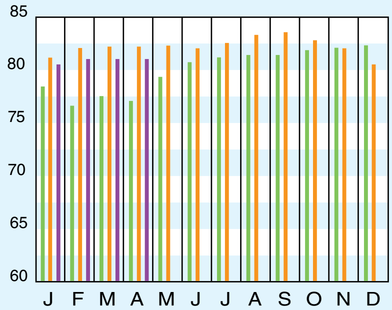
CURRENT BUSINESS INDICATORS	LATEST	PREVIOUS		YEAR AGO
CPI output index (2017 = 100)	Apr. '23 = 100.1	Mar. '23 = 99.6	Feb. '23 = 99.9	Apr. '22 = 101.2
CPI value of output, $ billions	Mar. '23 = 2,359.0	Feb. '23 = 2,421.0	Jan. '23 = 2,452.9	Mar. '22 = 2,473.0
CPI operating rate, %	Apr. '23 = 80.0	Mar. '23 = 79.6	Feb. '23 = 80.0	Apr. '22 = 81.8
Producer prices, industrial chemicals (1982 = 100)	Apr. '23 = 328.0	Mar. '23 = 326.4	Feb. '23 = 327.2	Apr. '22 = 358.8
Industrial Production in Manufacturing (2017 =100)*	Apr. '23 = 99.8	Mar. '23 = 98.9	Feb. '23 = 99.7	Apr. '22 = 100.8
Hourly earnings index, chemical & allied products (1992 = 100)	Mar. '23 = 217.0	Feb. '23 = 210.7	Jan. '23 = 211.6	Mar. '22 = 198.4
Productivity index, chemicals & allied products (1992 = 100)	Apr. '23 = 91.4	Mar. '23 = 92.0	Feb. '23 = 92.2	Apr. '22 = 93.5

CPI OUTPUT INDEX (2017 = 100)†

CPI OUTPUT VALUE ($ BILLIONS)



CPI OPERATING RATE (%)



*Due to discontinuance, the Index of Industrial Activity has been replaced by the Industrial Production in Manufacturing index from the U.S. Federal Reserve Board.
†For the current month's CPI output index values, the base year was changed from 2012 to 2017
Current business indicators provided by Global Insight, Inc., Lexington, Mass.

CURRENT TRENDS

The preliminary value for the *CE* Plant Cost Index (CEPCI; top) for April 2023 (most recent available) rose compared to the previous month's value, the second consecutive monthly rise. The April values saw small increases in all four subindices (Equipment; Buildings; Construction Labor; and Engineering & Supervision). The current CEPCI value now sits at 1.6% lower than the corresponding value from April 2022. Regarding the Current Business Indicators (middle), readers will notice a large increase in the CPI Output Values for 2023. This increase is likely the result of annual revisions made by the U.S. Census Bureau. Shipments of nondurable goods (including chemicals and fuels) were revised higher for the year.